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RESEARCH MEMORANDUM

THEORETICAL PERFORMANCE OF LIQUID HYDROGEN AND LIQUID
FLUORINE AS A ROCKET PROPELLANT FOR A
CHAMBER PRESSURE OF 600 POUNDS
PER SQUARE INCH ABSOLUTE

By Anthony Fortini and Vearl N. Huff

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THEORETICAL PERFORMANCE OF LIQUID HYDROGEN AND LIQUID FLUORINE
AS A ROCKET PROPELLANT FOR A CHAMBER PRESSURE OF
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SUMMARY

Theoretical rocket performance for frozen and equilibrium composition during expansion was calculated for the propellant combination of liquid hydrogen and liquid fluorine at a chamber pressure of 600 pounds per square inch absolute and several pressure ratios and oxidant-fuel ratios.

The parameters included were specific impulse, combustion-chamber temperature, nozzle-exit temperature, molecular weight, characteristic velocity, coefficient of thrust, ratio of nozzle-exit area to throat area, specific heat at constant pressure, isentropic exponent, viscosity, and thermal conductivity. A correlation is given for the effect of chamber pressure on several of the parameters.

INTRODUCTION

A continuing interest in liquid hydrogen and liquid fluorine as a rocket propellant is assured by extremely high specific impulse. Theoretical performance of liquid hydrogen with liquid fluorine has been reported in the literature (e.g., refs. 1 to 3). Reference 2 uses the previously accepted value of dissociation energy for fluorine F_2 (approx. 64 kcal/mole).

Additional computations were made for the hydrogen-fluorine propellant at the NACA Lewis laboratory from 1953 to 1955 as required for theoretical and experimental programs. These data were computed for both frozen and equilibrium composition during expansion and are based on the lower dissociation energy of fluorine F_2 (approx. 34 kcal/mole, ref. 4).

The present report presents the data for frozen and equilibrium composition during expansion for a chamber pressure of 600 pounds per square

inch absolute and a wide range of oxidant-fuel ratios and pressure ratios. A correlation is given which permits the determination of specific impulse, characteristic velocity, ratio of nozzle-exit area to throat area, chamber temperature, and nozzle-exit temperature for a wide range of chamber pressure.

SYMBOLS

The following symbols are used in this report:

- A nozzle area, sq in.
- a local velocity of sound (velocity of flow at throat), ft/sec
- C_F coefficient of thrust, $C_F = Ig_C/c^* = F/P_C A_t$
- C_p^o molar specific heat at constant pressure, cal/(mole)(°K)

$$c_p = \frac{\sum_i n_i (C_p^o)_i}{M}$$
 for frozen composition and $(\partial h/\partial T)_p$ for equilibrium or frozen composition, cal/(g)(°K)
- c^* characteristic velocity, $c^* = g_C P_C A_t / w$, ft/sec
- F thrust, lb
- g_C gravitational conversion factor, 32.174 (lb mass/lb force)(ft/sec²)
- H_T^o sum of sensible enthalpy and chemical energy, cal/mole
- h sum of sensible enthalpy and chemical energy per unit mass,

$$\frac{\sum_i n_i (H_T^o)_i}{M}$$
, cal/g
- I specific impulse, lb force-sec/lb mass
- k coefficient of thermal conductivity, cal/(sec)(cm)(°K)
- M molecular weight, $\sum_i n_i M_i$, g/g-mole or lb/lb-mole

n_c^* characteristic-velocity exponent, $\left(\frac{\Delta \log c^*}{\Delta \log P_c}\right)$ and $\frac{\partial \ln c^*}{\partial \ln P_c}$ for frozen and equilibrium composition, respectively

n_I specific-impulse exponent for fixed pressure ratio, $\left(\frac{\Delta \log I}{\Delta \log P_c}\right)_{P_c/P}$ and $\left(\frac{\partial \ln I}{\partial \ln P_c}\right)_{P_c/P}$ for frozen and equilibrium composition, respectively

n_i mole fraction of gaseous substance, i

n_T temperature exponent for fixed pressure ratio, $\left(\frac{\Delta \log T}{\Delta \log P_c}\right)_{P_c/P}$ and $\left(\frac{\partial \ln T}{\partial \ln P_c}\right)_{P_c/P}$ for frozen and equilibrium composition, respectively

n_ϵ area-ratio exponent for fixed pressure ratio, $\left(\frac{\Delta \log \epsilon}{\Delta \log P_c}\right)_{P_c/P}$ and $\left(\frac{\partial \ln \epsilon}{\partial \ln P_c}\right)_{P_c/P}$ for frozen and equilibrium composition, respectively

o/f oxidant-to-fuel weight ratio

P pressure, lb/sq in.

p partial pressure, lb/sq in.

R universal gas constant (consistent units)

r equivalence ratio, ratio of fluorine atoms to hydrogen atoms, F/H

S_T° entropy at 1 atmosphere pressure, cal/(mole)(°K)

s entropy per unit mass, $\frac{\sum_i n_i (S_T^\circ)_i}{M} - \frac{R \sum_i p_i \ln p_i / 14.696}{PM}$, cal/(g)(°K)

T temperature, °K

w mass-flow rate, lb/sec

γ isentropic exponent, $\left(\frac{\partial \ln P}{\partial \ln \rho}\right)_s$

- ϵ ratio of nozzle area to throat area, A/A_t
 μ dynamic viscosity, g/(cm)(sec) = poise
 ξ molecular-weight derivative, $(\frac{\partial \ln M}{\partial \ln T})_s$
 ρ density, lb/cu in.

Subscripts:

- c combustion chamber
e nozzle exit
i gaseous product of combustion
P constant pressure
 P_c/P constant pressure ratio
s constant entropy
t nozzle throat

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CALCULATION OF PERFORMANCE DATA

Performance data were obtained at a chamber pressure of 600 pounds per square inch absolute for a range of equivalence ratios and pressure ratios. These data were calculated assuming frozen and equilibrium composition during expansion.

The computations were carried out by means of the method described in reference 5 with modifications to adapt it for use with an IBM Card-Programmed Electronic Calculator. The machine was operated with floating-decimal-point notation and eight significant figures. The successive approximation process used in the calculations was continued until seven-figure accuracy was reached in the desired values of the assigned parameters (mass balance and pressure or entropy).

Assumptions

The calculations were based on the following usual assumptions: perfect gas law, adiabatic combustion at constant pressure, isentropic expansion, no friction, homogeneous mixing, and one-dimensional flow.

The products of combustion were assumed to be ideal gases: atomic hydrogen H, hydrogen H₂, atomic fluorine F, fluorine F₂, and hydrogen fluoride HF. The combustion products were assumed to be completely expanded within the exit nozzle; that is, ambient pressure equals exit pressure.

Initial Data

Thermodynamic data. - The thermodynamic data for all combustion products were taken from reference 5, which uses the lower dissociation energy of 35.6 kilocalories per mole for F₂. The base used in this report for assigning absolute values to enthalpy is the same as in reference 5.

Physical and thermochemical data. - The properties of the fuel used in these calculations were obtained from references 4 to 8 and are given in table I.

Viscosity data. - The approximate viscosity data for the individual combustion products were taken from reference 3.

Computation of Combustion Conditions

A combustion pressure of 600 pounds per square inch absolute was assigned. At this assigned pressure, the composition n_i, enthalpy h (including both chemical and sensible energy), and entropy s were determined for three temperatures at 100° K intervals. The temperatures were chosen to band the value of enthalpy for the propellant mixture h_c. The formulas used to calculate h and s are

$$h = \frac{\sum_i n_i (H_T^0)_i}{M} \quad (1)$$

$$s = \frac{\sum_i n_i (S_T^0)_i}{M} - \frac{1.98718 \sum_i p_i \ln p_i / 14.696}{PM} \quad (2)$$

Combustion composition corresponding to h_c was obtained by ordinary three-point interpolation of composition as a function of h. Entropy s_c corresponding to h_c was obtained by means of a three-point - three-slope interpolation of s as a function of h. The slope was obtained by means of the thermodynamic relation

$$\left(\frac{\partial s}{\partial h} \right)_P = \frac{1}{T} \quad (3)$$

The molecular weight of the combustion products M is defined and computed by the following equation:

$$M = \sum_i n_i M_i \quad (4)$$

This value of M is suitable for use in the gas law

$$P = \rho RT/M \quad (5)$$

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Computation of Exit Conditions

Calculation of parameters at assigned temperatures. - Exit temperatures were selected at 200° , 300° , or 400° K intervals to cover the range of pressure ratios from 1 to 1500. At these selected temperatures, the following data were computed assuming isentropic expansion and frozen or equilibrium composition: pressure, enthalpy, molecular weight, molecular-weight derivative, specific heat at constant pressure, isentropic exponent, absolute viscosity, thermal conductivity, nozzle-area ratio, coefficient of thrust, and specific impulse.

Interpolation of throat pressure, enthalpy, temperature, and molecular weight. - The interpolation technique and the functions used are the same as in references 3, 9, and 10.

The errors due to interpolation were checked for several cases. The values presented for enthalpy, entropy, and specific impulse appear to be correctly computed to all figures tabulated. The temperature and molecular weight may in some cases be in error by a few figures in the last place tabulated. However, because of uncertainties in thermodynamic data used, all values are probably tabulated to more places than are entirely significant.

Formulas

The formulas used in computing the various performance parameters are as follows:

Specific impulse, lb force-sec/lb mass:

$$I = 294.98 \sqrt{\frac{h_c - h_e}{1000}} \quad (6)$$

Throat area per unit mass-flow rate, (sq in.)(sec)/lb:

$$\frac{A_t}{w} = \frac{2781.6 T_t}{P_t M_t a} \quad (7)$$

Characteristic velocity, ft/sec:

$$c^* = g_c P_c (A_t/w) = 32.174 P_c (A_t/w) \quad (8)$$

Coefficient of thrust:

$$C_F = \frac{g_c I}{c^*} = \frac{32.174 I}{c^*} \quad (9)$$

Nozzle area per unit mass-flow rate, (sq in.)(sec)/lb:

$$\frac{A}{w} = \frac{86.455 T}{PMI} \quad (10)$$

Ratio of nozzle area to throat area:

$$\epsilon = \frac{A/w}{A_t/w} \quad (11)$$

Specific heat at constant pressure, cal/(g)(°K):

For frozen and equilibrium composition

$$c_p \equiv \left(\frac{\partial h}{\partial T} \right)_p \quad (12)$$

For frozen composition

$$c_p = \frac{\sum_i n_i (c_p^o)_i}{M} \quad (12)$$

Isentropic exponent:

For frozen and equilibrium composition

$$\gamma = \left(\frac{\partial \ln P}{\partial \ln \rho} \right)_s \quad \left. \right\} \quad (13)$$

For frozen composition

$$\gamma = \frac{c_p}{c_p - \frac{R}{M}} = \frac{c_p}{c_v}$$

Absolute viscosity, poises:

$$\mu = \frac{PM}{\sum_i \frac{p_i}{\mu_i/M_i}} \quad (14)$$

Coefficient of thermal conductivity, cal/(sec)(cm)(°K):

$$k = \mu \left(c_p + \frac{5}{4} \frac{R}{M} \right) \quad (15)$$

Molecular-weight derivative for equilibrium composition:

$$\xi = \left(\frac{\partial \ln M}{\partial \ln T} \right)_s = D_A - \frac{\sum_i p_i D_i}{P} \quad (16)$$

where D_A and D_i have the definitions of reference 5.

The values of viscosity and thermal conductivity for mixtures of combustion gases calculated by means of equations (14) and (15) are only approximate. When more reliable transport properties for the various products of combustion become available, a more rigorous procedure for computing the properties of mixtures may also be justified.

THEORETICAL PERFORMANCE DATA

Tables

The calculated values of the performance parameters and equilibrium composition of the combustion products are given in tables II to VII.

The properties of gases in the combustion chamber and the characteristic velocity are given in table II for each equivalence ratio. Table III presents the values of performance parameters at assigned temperatures and constant entropy. These values were computed directly and used to interpolate properties for assigned pressure ratios. The values of viscosity and thermal conductivity of the mixture are also given in this table as a function of temperature.

The performance parameters for small pressure ratios from 1 to 8 are given in table IV. These properties permit computations within the rocket nozzle and for finite combustion-chamber diameters. Properties at the throat may be found where the area ratio is 1.000.

The performance parameters for pressure ratios from 10 to 1500 are given in table V. This table gives sufficient data to permit interpolation of complete data for any pressure ratio within the range tabulated.

The specific-impulse and area-ratio values for expansion from chamber pressure to 1 atmosphere are summarized in table VI. The maximum values calculated for specific impulse for frozen and equilibrium composition are 380.9 and 392.5, respectively.

Table VII presents the composition of the combustion products at the combustion temperature and various assigned temperatures at constant entropy.

Curves

The performance parameters and thermodynamic properties are plotted in figures 1 to 8 for frozen and equilibrium composition.

Curves of specific impulse are presented in figure 1 for pressure ratios from 10 to 1500 as functions of percent by weight of fuel. The maximum values occur at about 19 percent by weight of fuel for frozen composition, whereas the maximum values shift from about 15 percent fuel at the low pressure ratios to about 7 percent fuel at the high pressure ratios for equilibrium composition.

Curves of combustion temperature and exit temperature for pressure ratios from 1 to 1500 are plotted in figure 2 as functions of percent by weight of fuel.

Curves of the ratio of nozzle area to throat area are plotted in figure 3 for pressure ratios from 10 to 1500 as functions of percent by weight of fuel.

Figure 4 gives the curves for coefficient of thrust for pressure ratios from 10 to 1500 as functions of percent by weight of fuel.

Curves of molecular weight for pressure ratios of 1 to 1500 as functions of percent by weight of fuel are presented in figure 5.

Figures 6 and 7 give a comparison of characteristic velocity and specific impulse, respectively, for complete expansion to 1 atmosphere during frozen or equilibrium composition. Also shown is the equilibrium performance for a chamber pressure of 300 pounds per square inch absolute from reference 3.

Figure 8 compares frozen and equilibrium values of specific heat and the isentropic exponent as a function of temperature for a stoichiometric mixture. At the higher temperature the specific heat for equilibrium composition is greater than for frozen composition, indicating that a major part of any energy added goes to dissociate the molecules. The frozen mixture, however, has a slightly higher specific heat at the lowest temperature because the average specific heat of the composition frozen at combustion conditions is greater than that of the equilibrium composition at low temperatures, which is undissociated.

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Chamber-Pressure Effect

The logarithmic values of the parameters I , T , ϵ , and c^* are very nearly linear with the logarithm of chamber pressure for a fixed equivalence ratio and pressure ratio. This linearity permits the data to be represented by means of exponential equations. For frozen composition the exponents can be found from data for two chamber pressures. In the case of equilibrium composition, however, the following analytic expressions that permit the exponents to be computed from data at a single chamber pressure have been derived (ref. 10):

$$n_I = \left(\frac{\partial \ln I}{\partial \ln P_c} \right)_{P_c/P} = 86.4554 \frac{T}{I^2} \left(\frac{1}{M_c} - \frac{1}{M} \right) \quad (16)$$

$$n_T = \left(\frac{\partial \ln T}{\partial \ln P_c} \right)_{P_c/P} = \left(\frac{\gamma-1}{\gamma} \right) \left(\frac{1}{1-\xi} \right) - \frac{R}{M_c c_p} \quad (17)$$

$$n_\epsilon = \left(\frac{\partial \ln \epsilon}{\partial \ln P_c} \right)_{P_c/P} = (n_{A/w})_e - (n_{A/w})_t \quad (18)$$

where

$$n_{A/w} = \left(\frac{\partial \ln A/w}{\partial \ln P_c} \right)_{P_c/P} = - \left(\frac{M}{M_c} \right) \left(\frac{\gamma-1}{\gamma} \right) \left(\frac{1}{1-\xi} \right) - \frac{1}{\gamma} - n_I$$

$$n_{c^*} = \frac{\partial \ln c^*}{\partial \ln P_c} = 1 + (n_A/w)_t \quad (19)$$

Equations (16) to (19) may be written as

$$I = I_1 \left(\frac{P_c}{600} \right)^{n_I,1} \quad (20)$$

$$T = T_1 \left(\frac{P_c}{600} \right)^{n_T,1} \quad (21)$$

$$\epsilon = \epsilon_1 \left(\frac{P_c}{600} \right)^{n_\epsilon,1} \quad (22)$$

$$c^* = c_1^* \left(\frac{P_c}{600} \right)^{n_{c^*},1} \quad (23)$$

where I_1 , T_1 , ϵ_1 , and c_1^* are the values of the parameter for a chamber pressure of 600 pounds per square inch.

To illustrate the use of these relations, suppose it is desired to obtain the value of specific impulse for a chamber pressure of 300 pounds per square inch absolute and a pressure ratio of 40.83 (exit pressure, 0.5 atm) for an equivalence ratio r of 1.00 (percent by weight of fuel, 5.038). From tables II and VI, the values obtained for use in equation (16) were $T = 3285$, $I = 374.7$, $M_c = 17.12$, and $M = 19.24$. Therefore,

$$n_I = 86.4554 \frac{3285}{(374.7)^2} \left(\frac{1}{17.12} - \frac{1}{19.24} \right)$$

$$n_I = 0.01305$$

From equation (20),

$$I = 374.7 \left(\frac{300}{600} \right)^{0.01305}$$

$$I = 371.3$$

The value of I for these conditions from reference 3, table III (chamber pressure, 300 lb/sq in. abs.; pressure ratio, 40.83; altitude, 17,971 ft; and equivalence ratio, 1.00) was 371.2; hence, the error by the use of the exponent equation is about 0.1 of an impulse unit.

Further detailed discussions with examples and comparisons for the use of these exponents are given in references 9 and 10.

SUMMARY OF RESULTS

A theoretical investigation of the performance of liquid hydrogen fuel with liquid fluorine as an oxidant was made for the following conditions:

- (1) Equivalence ratios from 1.20 to 0.15
- (2) Chamber pressure of 600 pounds per square inch absolute
- (3) Pressure ratios from 1 to 1500
- (4) Both frozen and equilibrium composition during expansion

The results of the investigation are as follows:

1. The maximum values of specific impulse for chamber pressures of 600 pounds per square inch absolute and an exit pressure of 1 atmosphere were 381.5 at a weight percent fuel of 18.5, and 392.5 at a weight percent fuel of 12.5 for frozen and equilibrium composition, respectively.
2. The data presented in this report permit interpolation of complete performance data for any equivalence ratio from 1.20 to 0.15, chamber pressure from 300 to 1200 pounds per square inch absolute, and pressure ratios up to 1500.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, December 11, 1956

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TABLE I. - PROPERTIES OF LIQUID PROPELLANTS

Properties	Hydrogen	Fluorine
Molecular weight, M	2.016	38.00
Density, g/cc	^a 0.0709 (at -252.7° C)	^b 1.54 (at -196° C)
Freezing point, °C	c-259.20	c-217.96
Boiling point, °C	c-252.77	c-187.92
Viscosity, centipoises	d0.0215 (at -258.33° C)	-----
Enthalpy of formation at boiling point from elements at 25° C, ΔH_f , kcal/mole	e-1.895	e-3.030
Enthalpy of vaporiza- tion ΔH , kcal/mole	c0.216 (at -252.77° C)	c1.51 (at -187.92° C)
Enthalpy of fusion, ΔH , kcal/mole	c0.028 (at -259.20° C)	c0.372 (at -217.96° C)

^aRef. 6.^bRef. 7.^cRef. 4.^dRef. 8.^eRef. 5.

TABLE II. - THERMODYNAMIC PROPERTIES OF COMBUSTION GASES
FOR HYDROGEN AND FLUORINE

[Chamber pressure, 600 lb/sq in. abs]

Equivalence ratio, $r, \frac{F}{H}$	Percent fuel by weight	Oxidant-to-fuel weight ratio, o/f	Temperature, T, °K	Molecular weight, M _C	Enthalpy h, cal/g (a)	Entropy s, cal (g) (°K)	Characteristic velocity, c*, ft/sec	
							Equilibrium composition (b)	Frozen composition (b)
1.20	4.233	22.62	4730	18.12	2931.6	2.909	7533	7163
1.10	4.601	20.73	4747	17.65	3048.9	2.984	7656	7278
1.00	5.038	18.85	4740	17.11	3188.4	3.072	7774	7396
.90	5.567	16.96	4703	16.49	3357.1	3.176	7887	7513
.80	6.219	15.08	4629	15.77	3565.4	3.301	7989	7630
.70	7.045	13.19	4505	14.95	3829.1	3.455	8075	7741
.60	8.124	11.31	4326	14.01	4173.5	3.648	8151	7846
.50	9.593	9.42	4090	12.93	4642.4	3.902	8234	7955
.40	11.710	7.54	3793	11.65	5318.4	4.251	8334	8084
.30	15.027	5.65	3388	10.06	6377.3	4.770	8427	8232
.20	20.965	3.77	2736	7.98	8273.1	5.635	8360	8292
.15	26.128	2.83	2242	6.71	9921.2	6.324	8169	8158

^aThe base used for enthalpy is given in ref. 5.

^bParameter includes energy due to change in composition.

TABLE III. - THEORETICAL ROCKET PERFORMANCE AT ASSIGNED TEMPERATURES FOR HYDROGEN
AND FLUORINE

(a) Frozen composition during isentropic expansion or compression from combustion conditions at a chamber pressure of 600 pounds per square inch absolute

Temperature, T , °K	Pressure, P , lb/sq in. abs	Enthalpy, h , cal/g	Isentropic exponent, γ	Specific heat, c_p , cal/ (g)(°K)	Absolute viscosity, μ , micro- poises	Thermal conductivity, K , cal/(cm) (sec)(°K)	Area ratio, ϵ	Thrust coefficient, C_f	Specific impulse, I , lb-sec lb
$r = 1.20$; percent fuel = 4.233; o/f = 22.82									
4800	636.076	2962.2	1.356	0.4356	2315	0.00133	----	----	----
4400	451.147	2788.9	1.342	0.4306	2143	0.00122	1.15	0.501	111.4
4000	310.915	2617.6	1.346	0.4262	1969	0.00111	1.00	.743	168.3
3600	206.917	2448.0	1.352	0.4216	1792	0.00100	1.09	.921	205.1
3200	131.846	2280.4	1.358	0.4163	1614	0.00089	1.31	1.069	238.1
2800	79.778	2115.0	1.365	0.4101	1432	0.00078	1.69	1.197	268.6
2400	45.065	1852.5	1.375	0.4026	1247	0.00067	2.35	1.311	291.9
2000	23.266	1783.5	1.387	0.3928	1058	0.00056	3.51	1.414	314.7
1600	10.595	1658.6	1.405	0.3805	865	0.00045	5.79	1.507	335.4
1200	5.983	1489.5	1.428	0.3650	686	0.00035	10.94	1.591	354.3
900	1.546	1381.0	1.444	0.3565	512	0.00025	20.38	1.680	367.3
600	.418	1274.7	1.451	0.3527	353	0.00017	48.64	1.706	379.7
$r = 1.10$; percent fuel = 4.601; o/f = 20.73									
4800	627.518	3072.8	1.352	0.4516	2321	0.00138	----	0.514	116.4
4400	443.409	2893.2	1.337	0.4463	2147	0.00126	1.11	.753	170.3
4000	304.473	2715.6	1.342	0.4417	1971	0.00115	1.00	.930	210.4
3600	201.843	2539.9	1.347	0.4367	1793	0.00104	1.10	.922	243.7
3200	128.175	2388.3	1.353	0.4312	1613	0.00092	1.35	1.077	272.6
2800	77.147	2195.1	1.361	0.4248	1429	0.00081	1.73	1.205	298.2
2400	43.365	2026.8	1.370	0.4166	1243	0.00069	2.41	1.318	321.3
2000	22.267	1882.1	1.383	0.4063	1065	0.00058	3.85	1.420	342.3
1600	10.080	1702.1	1.401	0.3933	859	0.00046	6.02	1.513	361.4
1200	5.765	1547.9	1.424	0.3779	660	0.00034	11.45	1.598	384.5
900	1.454	1436.1	1.441	0.3678	507	0.00026	21.46	1.686	394.5
600	.390	1326.6	1.449	0.3635	348	0.00018	51.56	1.711	394.5
$r = 1.00$; percent fuel = 5.038; o/f = 18.85									
4800	631.303	3216.5	1.327	0.4707	2325	0.00143	----	0.512	117.6
4400	444.825	3029.4	1.333	0.4651	2149	0.00131	1.11	.753	173.0
4000	304.145	2844.3	1.337	0.4601	1971	0.00119	1.00	.930	214.1
3600	200.808	2681.3	1.343	0.4549	1792	0.00108	1.10	.922	248.2
3200	126.961	2480.5	1.349	0.4490	1610	0.00096	1.34	1.080	277.7
2800	76.059	2302.5	1.356	0.4420	1425	0.00084	1.75	1.208	293.9
2400	42.534	2127.1	1.366	0.4354	1258	0.00072	2.45	1.322	320.6
2000	21.719	1955.8	1.379	0.4225	1047	0.00059	3.71	1.425	347.5
1800	9.772	1789.5	1.397	0.4066	853	0.00047	6.19	1.518	368.9
1200	3.626	1629.3	1.420	0.3923	654	0.00035	11.85	1.602	386.3
900	1.392	1515.3	1.438	0.3814	501	0.00026	22.35	1.681	381.8
600	.372	1399.8	1.446	0.3766	345	0.00017	55.97	1.716	394.5
$r = 0.90$; percent fuel = 5.587; o/f = 16.96									
4800	652.068	3404.8	1.325	0.4940	2325	0.00150	----	0.512	113.7
4400	457.480	3208.4	1.328	0.4879	2147	0.00137	1.14	.740	172.7
4000	311.665	3014.3	1.333	0.4826	1968	0.00125	1.00	.924	215.7
3600	204.882	2822.4	1.338	0.4770	1786	0.00112	1.10	.903	251.5
3200	128.937	2632.8	1.344	0.4706	1605	0.00100	1.35	1.075	281.6
2800	76.856	2446.0	1.352	0.4631	1418	0.00087	1.74	1.206	308.6
2400	42.761	2262.8	1.361	0.4559	1230	0.00074	2.45	1.322	332.9
2000	21.689	2083.2	1.375	0.4422	1059	0.00062	3.73	1.426	352.9
1800	9.700	1909.2	1.393	0.4273	845	0.00049	6.26	1.520	364.9
1200	5.574	1741.8	1.417	0.4098	646	0.00036	12.06	1.605	374.9
900	1.384	1620.7	1.434	0.3980	494	0.00027	22.86	1.685	388.7
600	.382	1502.3	1.443	0.3926	357	0.00018	55.62	1.720	401.7
$r = 0.80$; percent fuel = 6.218; o/f = 15.08									
4800	697.497	3654.9	1.317	0.5228	2315	0.00158	----	0.487	113.7
4400	487.243	3447.1	1.323	0.5163	2136	0.00144	1.23	.740	172.7
4000	350.432	3241.7	1.328	0.5105	1957	0.00131	1.00	.708	167.8
3600	216.171	3058.7	1.333	0.5043	1775	0.00118	1.08	.693	214.1
3200	135.342	2883.8	1.339	0.4974	1592	0.00104	1.30	1.081	251.5
2800	80.229	2641.0	1.347	0.4893	1406	0.00091	1.71	1.196	283.6
2400	44.357	2447.2	1.357	0.4793	1218	0.00078	2.41	1.315	311.9
2000	22.370	2257.9	1.370	0.4687	1028	0.00064	3.68	1.422	337.3
1600	9.929	2074.3	1.388	0.4505	834	0.00051	6.20	1.519	360.2
1200	5.630	1897.9	1.412	0.4315	637	0.00038	12.03	1.606	380.9
900	1.377	1770.4	1.430	0.4168	486	0.00028	22.94	1.687	395.2
600	.362	1645.9	1.440	0.4126	331	0.00019	56.20	1.725	408.7
$r = 0.70$; percent fuel = 7.045; o/f = 13.19									
4800	782.625	3995.4	1.312	0.5596	2288	0.00166	----	0.296	71.1
4400	543.899	3771.0	1.317	0.5525	2111	0.00152	1.84	.645	155.5
4000	366.857	3551.3	1.322	0.5460	1935	0.00138	1.01	.622	207.5
3600	238.628	3334.2	1.327	0.5392	1752	0.00124	1.05	.603	248.4
3200	148.495	3120.1	1.334	0.5315	1570	0.00110	1.25	1.032	282.9
2800	87.454	2909.2	1.341	0.5225	1387	0.00098	1.63	1.176	313.1
2400	46.014	2702.4	1.351	0.5115	1201	0.00082	2.30	1.301	340.0
2000	24.031	2500.4	1.364	0.4978	1012	0.00067	3.53	1.413	364.2
1600	10.579	2304.8	1.385	0.4799	821	0.00055	5.99	1.514	388.0
1200	3.833	2118.9	1.408	0.4591	626	0.00039	11.70	1.604	401.0
900	1.443	1981.4	1.426	0.4451	477	0.00029	22.44	1.686	415.1
600	.378	1849.1	1.436	0.4381	325	0.00020	55.43	1.725	415.1

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TABLE III. - Continued. THEORETICAL ROCKET PERFORMANCE AT ASSIGNED TEMPERATURES FOR HYDROGEN AND FLUORINE

(a) Concluded. Frozen composition during isentropic expansion or compression from combustion conditions at a chamber pressure of 600 pounds per square inch absolute

4346

Cx-3

Temperature, T_{K}	Pressure, P, lb/sq in. abs	Enthalpy, h, cal/g	Isentropic exponent, γ	Specific heat, c_p , cal (g) $(^{\circ}\text{K})$	Absolute viscosity, μ , micro- poises	Thermal conductivity, K, cal/(cm) (sec) $(^{\circ}\text{K})$	Area ratio, e	Thrust coeffi- cient, C_F	Specific impulse, I, lb-sec lb
$r = 0.60$; percent fuel = 8.124; o/f = 11.31									
4400	644.830	4,218.1	1.310	0.6000	2062	0.00160	----	----	----
4000	431.929	3,979.5	1.315	.5927	1888	.00145	1.08	0.533	129.9
3600	278.912	3,744.0	1.320	.5848	1712	.00131	1.01	.793	193.3
3200	172.227	3,511.8	1.327	.5761	1535	.00116	1.18	.984	240.0
2800	100.600	3,283.3	1.334	.5680	1356	.00101	1.52	1.141	278.3
2400	54.744	3,059.3	1.344	.5536	1174	.00086	2.14	1.277	311.4
2000	27.138	2,840.9	1.358	.5380	990	.00071	3.29	1.396	340.5
1600	11.823	2,629.5	1.377	.5182	803	.00056	5.60	1.503	366.5
1200	4.235	2,426.8	1.402	.4950	613	.00041	11.03	1.599	389.9
900	1.578	2,280.8	1.420	.4794	467	.00031	21.33	1.664	405.8
600	.407	2,138.3	1.430	.4715	318	.00021	53.24	1.726	420.8
$r = 0.50$; percent fuel = 9.593; o/f = 9.42									
4400	821.444	4,847.3	1.300	0.6651	1982	0.00170	----	----	----
4000	545.243	4,585.0	1.306	.6565	1816	.00154	1.65	0.291	71.9
3600	348.730	4,322.2	1.311	.6472	1649	.00138	1.00	.675	166.9
3200	213.178	4,065.3	1.318	.6370	1480	.00123	1.09	.906	224.1
2800	123.191	3,812.8	1.326	.6251	1309	.00107	1.37	1.087	268.7
2400	66.271	3,565.5	1.336	.6108	1135	.00091	1.92	1.238	306.1
2000	32.447	3,324.7	1.350	.5929	959	.00075	2.95	1.370	338.6
1600	13.946	3,091.9	1.369	.5701	779	.00059	5.07	1.486	367.3
1200	4.922	2,889.1	1.394	.5436	596	.00044	10.07	1.589	392.8
900	1.811	2,708.8	1.413	.5258	455	.00033	19.66	1.659	410.2
600	.459	2,552.6	1.425	.5168	310	.00022	49.75	1.725	426.4
$r = 0.40$; percent fuel = 11.710; o/f = 7.54									
4000	757.340	5,473.1	1.295	0.7487	1712	0.00165	----	----	----
3600	478.590	5,175.9	1.301	.7373	1557	.00148	1.20	0.443	111.4
3200	288.873	4,885.4	1.308	.7248	1400	.00131	1.01	.774	194.5
2800	164.700	4,596.3	1.316	.7105	1241	.00115	1.20	.998	250.7
2400	87.332	4,315.4	1.326	.6933	1079	.00098	1.65	1.176	295.4
2000	42.098	4,042.2	1.340	.6719	915	.00081	2.53	1.326	335.2
1600	17.791	3,778.7	1.360	.6449	746	.00064	4.35	1.457	366.0
1200	6.162	3,527.0	1.385	.6136	573	.00047	8.74	1.571	394.8
900	2.231	3,346.1	1.404	.5927	439	.00035	17.26	1.649	414.3
600	.554	3,170.2	1.414	.5821	301	.00024	44.42	1.721	432.3
$r = 0.30$; percent fuel = 15.027; o/f = 5.65									
3600	785.462	6,563.2	1.290	0.8789	1427	0.00161	----	----	----
3200	467.366	6,214.8	1.297	.8628	1288	.00143	1.16	0.465	118.9
2800	262.461	5,873.2	1.305	.8446	1146	.00125	1.03	.819	209.4
2400	136.932	5,539.5	1.316	.8230	1001	.00107	1.31	1.055	270.0
2000	64.867	5,215.5	1.330	.7961	852	.00089	1.95	1.243	317.9
1600	26.901	4,903.6	1.350	.7626	699	.00071	3.35	1.400	358.1
1200	9.125	4,606.2	1.375	.7240	541	.00053	6.75	1.534	392.6
900	3.244	4,395.1	1.394	.6984	417	.00039	13.46	1.624	415.5
$r = 0.20$; percent fuel = 20.965; o/f = 3.77									
2800	663.203	8,342.1	1.297	1.0866	1005	0.00141	----	----	----
2400	341.520	7,913.1	1.308	1.0574	884	.00121	1.00	0.687	177.0
2000	159.550	7,497.1	1.322	1.0214	758	.00101	1.22	1.008	259.8
1600	65.185	7,097.2	1.342	.9766	628	.00081	1.94	1.241	319.9
1200	21.754	6,716.8	1.368	.9255	491	.00061	3.78	1.428	368.0
900	7.623	6,444.4	1.387	.8919	383	.00046	7.46	1.548	398.9
600	1.814	6,179.7	1.398	.8751	269	.00032	19.54	1.656	426.8
$r = 0.15$; percent fuel = 26.128; o/f = 2.83									
2400	800.365	10,119.3	1.307	1.2630	802	0.00131	----	----	----
2000	372.891	9,622.5	1.321	1.2195	692	.00110	1.01	0.636	161.2
1600	151.925	9,145.2	1.341	1.1654	576	.00099	1.24	1.025	259.9
1200	50.557	8,691.3	1.367	1.1040	455	.00067	2.21	1.290	327.1
900	17.671	8,366.4	1.386	1.0638	358	.00051	4.22	1.451	367.8
600	4.191	8,050.7	1.396	1.0438	254	.00036	10.82	1.591	403.4

TABLE III. - Continued. THEORETICAL ROCKET PERFORMANCE AT ASSIGNED TEMPERATURES FOR HYDROGEN AND FLUORINE

(b) Equilibrium composition during isentropic expansion or compression from combustion conditions at a chamber pressure of 600 pounds per square inch absolute

Temperature, T , °K	Pressure, P , lb/sq in. abs	Enthalpy, h , cal/g	Molecular weight, M	Partial deriva- tive, $(\frac{\partial \ln M}{\partial \ln T})_S$	Isentropic exponent, γ $(\frac{\partial \ln P}{\partial \ln T})_S$	Specific heat, c_p , cal (g)(°K)	Absolute viscosity, μ , micro- poises	Thermal conduc- tivity, K , cal/(cm) (sec)(°K)	Area ratio, e	Thrust coeffi- cient, C_F	Specific impulse, I , lb-sec lb
$r = 1.20$; percent fuel = 4.233; o/f = 22.82											
4800	689.065	3,004.2	18.03	-0.3502	1.169	1.9793	2308	0.00489	-----	-----	-----
4400	302.778	2,593.5	18.57	-0.3263	1.163	1.7928	2171	0.00418	1.01	0.735	171.5
4000	124.489	2,199.9	19.11	-0.2710	1.164	1.4475	2019	0.00319	1.48	1.078	252.3
3600	51.768	1,857.0	19.56	-0.1637	1.186	0.9486	1852	0.00199	2.58	1.306	305.8
3200	24.977	1,606.2	19.79	-0.0451	1.258	0.5425	1667	0.00111	4.22	1.450	339.6
2800	13.711	1,425.6	19.84	-0.0043	1.320	0.168	1473	0.00080	6.30	1.546	362.0
2400	7.377	1,264.4	19.84	-0.0002	1.359	0.3956	1276	0.00067	9.54	1.627	380.9
2000	3.629	1,108.5	19.84	-0.0001	1.353	0.3843	1076	0.00055	15.45	1.701	398.3
1600	1.565	957.4	19.84	-0.0010	1.370	0.3717	872	0.00043	27.54	1.770	414.5
1200	.537	808.6	19.88	-0.0256	1.351	0.4079	665	0.00035	57.95	1.836	429.8
$r = 1.10$; percent fuel = 4.601; o/f = 20.73											
4800	687.861	3,106.6	17.58	-0.3560	1.165	2.1873	2316	0.00539	-----	-----	-----
4400	284.019	2,669.3	18.14	-0.3514	1.157	2.0653	2180	0.00481	1.02	0.764	181.7
4000	109.095	2,236.4	18.73	-0.3195	1.152	1.8230	2031	0.00337	1.60	1.117	265.9
3600	39.074	1,828.9	19.31	-0.2503	1.156	1.3999	1866	0.00265	3.19	1.369	325.3
3200	14.794	1,492.5	19.75	-0.1208	1.192	0.8222	1684	0.00160	6.49	1.547	368.0
2800	7.028	1,268.1	19.90	-0.0168	1.284	0.4682	1485	0.00088	11.09	1.654	393.6
2400	3.547	1,097.9	19.92	-0.0006	1.324	0.4085	1283	0.00068	17.46	1.731	412.0
2000	1.753	937.5	19.92	-0.0000	1.339	0.3946	1077	0.00056	29.14	1.801	428.6
1600	.738	782.6	19.92	-0.0001	1.357	0.3794	870	0.00044	53.45	1.866	444.1
1200	.253	633.9	19.92	-0.0040	1.375	0.3692	660	0.00035	113.28	1.926	458.4
$r = 1.00$; percent fuel = 5.038; o/f = 18.85											
4800	678.343	3,256.5	17.04	-0.3658	1.163	2.3166	2319	0.00571	-----	-----	-----
4400	285.586	2,799.9	17.58	-0.3573	1.155	2.2243	2183	0.00516	1.02	0.761	183.8
4000	107.262	2,545.1	18.17	-0.3345	1.148	2.0297	2034	0.00441	1.82	1.122	271.2
3600	36.195	1,899.4	18.78	-0.2891	1.145	1.7088	1871	0.00345	3.39	1.386	334.9
3200	11.513	1,493.6	19.35	-0.2111	1.153	1.2726	1651	0.00237	8.03	1.589	384.0
2800	3.867	1,160.8	19.77	-0.1077	1.184	0.8227	1498	0.00142	18.72	1.758	420.0
2400	1.526	918.6	19.96	-0.0291	1.251	0.5287	1290	0.00084	38.06	1.839	444.4
2000	.662	735.9	20.00	-0.0034	1.311	0.4217	1079	0.00059	70.17	1.912	462.0
1600	.268	574.5	20.01	-0.0001	1.341	0.3908	856	0.00045	134.39	1.974	476.9
1200	.089	422.4	20.01	-0.0000	1.387	0.3700	653	0.00032	294.43	2.050	490.6
$r = 0.90$; percent fuel = 5.567; o/f = 16.98											
4800	729.803	3,469.6	16.37	-0.3551	1.165	2.3410	2314	0.00577	-----	-----	-----
4400	312.068	3,002.9	16.88	-0.3434	1.157	2.2179	2177	0.00515	1.01	0.761	175.6
4000	120.572	2,540.4	17.42	-0.3152	1.152	1.9768	2026	0.00429	1.51	1.088	266.6
3600	42.990	2,100.3	17.96	-0.2615	1.154	1.5977	1859	0.00323	2.98	1.349	330.7
3200	15.139	1,712.8	18.44	-0.1803	1.170	1.1422	1675	0.00214	6.41	1.543	378.3
2800	5.728	1,401.2	18.78	-0.0998	1.204	0.7852	1477	0.00136	13.35	1.683	412.5
2400	2.350	1,157.1	18.97	-0.0400	1.252	0.5693	1272	0.00089	26.04	1.785	437.5
2000	1.000	980.7	19.05	-0.0082	1.304	0.4555	1064	0.00062	48.67	1.863	456.6
1600	.400	789.3	19.06	-0.0006	1.340	0.4118	856	0.00046	93.89	1.928	472.7
1200	.133	629.4	19.06	-0.0000	1.387	0.3884	646	0.00034	205.50	1.987	487.2
$r = 0.80$; percent fuel = 6.219; o/f = 15.08											
4400	373.397	3,297.9	16.03	-0.3168	1.163	2.1023	2157	0.00487	-----	-----	-----
4000	153.261	2,841.3	16.50	-0.2838	1.181	1.8260	2002	0.00396	1.32	1.011	251.0
3600	59.591	2,415.0	16.96	-0.2340	1.167	1.4770	1830	0.00297	2.35	1.274	316.4
3200	22.772	2,036.3	17.37	-0.1745	1.180	1.1403	1644	0.00211	4.63	1.469	364.8
2800	8.795	1,712.9	17.70	-0.1099	1.204	0.8557	1448	0.00144	9.36	1.617	401.5
2400	3.535	1,448.3	17.91	-0.0466	1.246	0.6239	1248	0.00095	18.45	1.729	429.2
2000	1.481	1,236.5	17.99	-0.0098	1.301	0.4877	1046	0.00066	34.83	1.813	450.2
1600	.591	1,054.3	18.01	-0.0007	1.339	0.4364	843	0.00048	67.23	1.883	467.4
1200	.196	885.1	18.01	-0.0000	1.387	0.4112	637	0.00035	146.84	1.945	482.9
$r = 0.70$; percent fuel = 7.045; o/f = 13.19											
4400	487.839	3,707.0	15.05	-0.2890	1.172	1.9845	2119	0.00456	-----	-----	-----
4000	213.015	3,253.8	15.45	-0.2803	1.172	1.7402	1980	0.00373	1.12	0.891	223.7
3600	88.053	2,827.8	15.85	-0.2224	1.176	1.4698	1787	0.00291	1.61	1.176	295.2
3200	34.904	2,438.2	16.23	-0.1743	1.185	1.1969	1604	0.00217	3.56	1.586	347.9
2800	13.598	2,095.2	16.54	-0.1120	1.204	0.9183	1414	0.00151	6.62	1.548	388.4
2400	5.458	1,811.7	16.74	-0.0474	1.245	0.6697	1220	0.00100	12.96	1.669	419.0
2000	2.283	1,584.7	16.82	-0.0099	1.301	0.5225	1025	0.00069	24.36	1.761	441.9
1600	.910	1,389.7	16.83	-0.0007	1.339	0.4670	827	0.00051	46.86	1.836	460.7
1200	.302	1,208.6	16.83	-0.0000	1.387	0.4399	627	0.00037	102.02	1.902	477.5

TABLE III. - Concluded. THEORETICAL ROCKET PERFORMANCE AT ASSIGNED TEMPERATURES FOR HYDROGEN AND FLUORINE

(b) Concluded. Equilibrium composition during isentropic expansion or compression from combustion conditions at a chamber pressure of 600 pounds per square inch absolute

Temperature, T , $^{\circ}\text{K}$	Pressure, P , 1b/sq in. abs	Enthalpy, H , cal/g	Molecular Weight, M	Partial deriva- tive, $(\frac{\partial \ln M}{\partial \ln T})_S$	Isentropic exponent, γ $(\frac{\partial \ln P}{\partial \ln T})_S$	Specific heat, c_p , cal (g)/ $^{\circ}\text{K}$	Absolute viscosity, μ , micro- poises	Thermal conduc- tivity, K , cal/(cm) (sec) $^{\circ}\text{K}$	Area ratio, s	Thrust coeffi- cient, C_F	Specific impulse, I , lb-sec lb
$r = 0.60$; percent fuel = 8.124; o/f = 11.31											
4400	690.427	4,260.5	13.95	-0.2667	1.182	1.9273	2059	0.00434	----	----	----
4000	516.412	3,799.6	14.29	-0.2447	1.181	1.7353	1800	.00362	1.00	0.712	180.4
3600	316.135	3,359.6	14.64	-0.2138	1.183	1.5117	1750	.00291	1.39	1.050	266.1
3200	55.431	2,850.0	14.98	-0.1687	1.189	1.2563	1553	.00221	2.42	1.288	326.5
2800	22.004	2,585.7	15.26	-0.1069	1.208	.9706	1371	.00155	4.58	1.467	371.7
2400	8.982	2,285.2	15.43	-0.0444	1.249	.7143	1185	.00104	8.76	1.601	405.6
2000	5.777	2,039.0	15.50	-0.0092	1.302	.5642	997	.00072	16.23	1.701	431.0
1600	1.508	1,827.7	15.51	-0.0006	1.339	.5066	807	.00054	51.01	1.783	451.8
1200	.501	1,631.2	15.51	-0.0000	1.367	.4774	614	.00039	67.21	1.856	470.3
900	.175	1,490.7	15.51	-0.0000	1.386	.4598	466	.00029	140.32	1.907	483.2
$r = 0.50$; percent fuel = 9.593; o/f = 9.42											
4000	504.249	4,554.7	13.00	-0.2292	1.188	1.7688	1818	0.00356	----	----	----
3600	224.479	4,070.2	15.30	-0.2002	1.188	1.5646	1656	.00290	1.10	0.872	223.2
3200	94.382	3,634.8	15.58	-0.1555	1.195	1.5084	1488	.00222	1.71	1.157	296.1
2800	38.712	5,247.0	15.81	-0.0957	1.214	1.0180	1316	.00158	3.05	1.562	348.5
2400	16.215	2,925.1	15.95	-0.0385	1.255	.7646	1141	.00108	5.56	1.511	386.8
2000	6.930	2,657.3	14.00	-0.0078	1.304	.6186	963	.00077	10.05	1.624	415.6
1600	2.774	2,424.1	14.01	-0.0005	1.339	.5604	781	.00058	18.99	1.717	439.3
1200	.922	2,206.6	14.01	-0.0000	1.367	.5285	597	.00042	40.89	1.799	460.4
900	.322	2,051.1	14.01	-0.0000	1.386	.5091	455	.00031	85.04	1.856	474.9
$r = 0.40$; percent fuel = 11.710; o/f = 7.54											
4000	887.979	5,580.3	11.53	-0.2075	1.195	1.8213	1709	0.00348	----	----	----
3600	410.882	5,080.9	11.76	-0.1783	1.196	1.6174	1558	.00285	1.04	0.555	143.8
3200	180.482	4,615.1	11.98	-0.1342	1.203	1.3572	1403	.00222	1.20	.956	247.7
2800	77.604	4,196.3	12.16	-0.0791	1.224	1.0714	1244	.00159	1.90	1.206	312.5
2400	35.785	3,844.3	12.26	-0.0308	1.264	.8322	1082	.00112	3.24	1.583	358.1
2000	14.705	3,548.3	12.29	-0.0061	1.308	.6960	917	.00082	5.65	1.515	392.5
1600	5.910	3,283.8	12.30	-0.0004	1.340	.6379	747	.00063	10.48	1.624	420.8
1200	1.955	3,036.0	12.30	-0.0000	1.367	.6022	574	.00046	22.32	1.721	445.6
900	.687	2,858.8	12.30	-0.0000	1.386	.5801	440	.00034	46.13	1.786	462.6
$r = 0.30$; percent fuel = 15.027; o/f = 5.65											
5600	896.621	6,655.7	9.98	-0.1458	1.206	1.6788	1426	0.00275	----	----	----
5200	417.649	6,142.3	10.12	-0.1049	1.216	1.4216	1272	.00212	1.05	0.546	143.0
4800	190.753	5,685.6	10.23	-0.0586	1.238	1.1542	1146	.00160	1.16	.938	245.7
4400	86.908	5,288.0	10.30	-0.0217	1.275	.9405	1002	.00118	1.73	1.175	307.9
4000	38.599	4,944.2	10.32	-0.0042	1.312	.8181	853	.00090	2.82	1.348	353.1
3600	15.576	4,630.5	10.32	-0.0003	1.340	.7594	700	.00070	5.06	1.488	389.9
3200	5.179	4,335.3	10.32	-0.0000	1.367	.7176	541	.00052	10.55	1.609	421.5
$r = 0.20$; percent fuel = 20.965; o/f = 3.77											
2800	673.496	8,352.7	7.97	-0.0559	1.257	1.3243	1005	0.00164	----	----	----
2400	321.796	7,875.4	8.00	-0.0127	1.287	1.1468	884	.00129	1.00	0.716	186.0
2000	145.768	7,443.7	8.01	-0.0024	1.315	1.0399	758	.00102	1.27	1.034	268.6
1600	59.046	7,041.6	8.01	-0.0002	1.340	.9771	628	.00081	2.06	1.260	327.3
1200	19.635	6,661.4	8.01	-0.0000	1.367	.9242	491	.00061	4.07	1.441	374.5
$r = 0.15$; percent fuel = 26.128; o/f = 2.83											
2400	808.762	10,126.5	6.70	-0.0085	1.293	1.3344	802	0.00137	----	----	----
2000	369.676	9,617.1	6.71	-0.0016	1.317	1.2547	692	.00111	1.01	0.641	162.7
1600	149.993	9,137.7	6.71	-0.0001	1.340	1.1665	576	.00089	1.24	1.028	261.1
1200	49.883	8,685.7	6.71	-0.0000	1.367	1.1038	455	.00067	2.23	1.292	328.1
1000	25.515	8,465.8	6.71	-0.0000	1.380	1.0756	391	.00057	3.35	1.402	355.9
900	17.429	8,358.9	6.71	-0.0000	1.386	1.0636	358	.00061	4.26	1.452	368.7

TABLE IV. - THEORETICAL ROCKET PERFORMANCE AT ASSIGNED PRESSURE RATIOS FROM 1 TO 8
FOR HYDROGEN AND FLUORINE

(a) Frozen composition during isentropic expansion or compression for a chamber pressure of 600 pounds per square inch absolute														
Pressure ratio, P_o/P	Pressure, lb/sq in. abs	Temperature, T , °K	Enthalpy, cal/g	Area ratio, A_e	Thrust coefficient, C_p	Specific impulse, $I_{lb\text{-sec}}$	Pressure ratio, P_o/P	Pressure, lb/sq in. abs	Temperature, T , °K	Enthalpy, cal/g	Area ratio, A_e	Thrust coefficient, C_p	Specific impulse, $I_{lb\text{-sec}}$	
$r = 1.20$; percent fuel = 4.233; $o/f = 22.62$						$r = 0.80$; percent fuel = 8.124; $o/f = 11.31$								
1.000	600.00	4750	2951.6	-----	0.095	21.2	1.000	600.00	4726	4175.5	-----	0.094	25.0	
1.010	594.06	4718	2928.5	4.822	0.095	21.2	1.010	594.06	4715	4167.4	4.788	0.094	25.0	
1.020	588.24	4708	2921.4	5.446	0.124	29.9	1.020	588.24	4705	4161.4	5.421	0.125	32.5	
1.040	576.92	4683	2911.4	2.482	0.189	42.0	1.040	576.92	4288	4149.5	2.470	0.187	45.7	
1.100	545.45	4617	2882.8	1.670	0.295	65.2	1.100	545.45	4229	4115.7	1.659	0.291	70.9	
1.200	500.00	4517	2859.2	1.298	0.403	89.7	1.200	500.00	4142	4084.0	1.289	0.400	97.6	
1.451	419.17	4518	2753.8	1.065	0.559	124.4	1.418	423.01	3980	3957.7	1.067	0.549	155.8	
1.551	386.93	4231	2716.3	1.027	0.615	136.9	1.537	390.47	3904	3925.0	1.028	0.605	147.6	
1.692	354.88	4158	2678.5	1.007	0.670	149.7	1.676	357.93	3824	3875.3	1.007	0.661	181.1	
1.881	322.44	4058	2635.5	1.000	0.724	151.0	1.844	325.34	3737	3824.2	1.000	0.718	174.3	
2.058	289.19	3930	2592.5	0.906	0.777	173.0	2.049	306.54	3635	3767.0	0.907	0.789	187.6	
2.258	257.85	3812	2551.8	1.028	0.812	185.2	2.305	327.40	3709.1	3247	3645.1	1.028	0.801	214.8
2.658	225.71	3882	2482.7	1.062	0.888	197.6	2.634	227.76	3427	3645.1	1.063	0.881	214.8	
4.000	150.00	3310	2328.2	1.236	1.031	229.5	4.000	150.00	3093	3450.1	1.248	1.029	250.9	
6.000	100.00	2974	2186.6	1.502	1.144	254.6	6.000	100.00	2798	3280.8	1.525	1.143	278.7	
8.000	75.00	2754	2098.2	1.752	1.211	269.8	8.000	75.00	2800	3170.8	1.782	1.211	295.4	
$r = 1.10$; percent fuel = 4.601; $o/f = 20.73$						$r = 0.50$; percent fuel = 9.393; $o/f = 9.42$								
1.000	600.00	4747	3048.9	-----	0.095	21.5	1.000	600.00	4090	4642.4	-----	0.094	23.5	
1.010	594.06	4755	3043.6	4.817	0.095	21.5	1.010	594.06	4081	4638.0	3.416	0.133	32.9	
1.020	588.24	4724	3038.3	5.442	0.134	50.5	1.020	588.24	4053	4617.9	2.467	0.187	46.2	
1.040	576.92	4701	3028.2	2.484	0.188	42.6	1.040	576.92	4000	4583.1	1.857	0.280	71.8	
1.100	545.45	4655	2998.5	1.688	0.293	68.2	1.100	545.45	3920	4530.2	1.287	0.400	98.8	
1.449	419.17	4410	2827.3	1.025	0.557	127.0	1.416	408.67	3452.0	4.772	0.094	23.5		
1.548	391.52	4283	2827.3	0.927	0.577	138.7	1.534	391.52	3637	3824.2	1.000	0.646	135.1	
1.689	355.23	4180	2786.4	1.007	0.658	151.1	1.673	355.23	3624	3437.7	1.007	0.659	122.8	
1.888	322.94	4060	2742.3	1.000	0.722	183.3	1.840	322.94	3543	4285.2	1.000	0.713	176.3	
2.084	290.84	3953	2684.8	1.006	0.776	175.5	2.045	285.42	3545	4228.6	1.007	0.764	189.8	
2.322	258.35	3856	2643.2	1.026	0.831	187.9	2.300	260.82	3539	4168.8	1.027	0.823	203.4	
2.654	226.06	3708	2586.5	1.062	0.887	200.8	2.628	228.22	3253	4099.1	1.064	0.879	217.4	
4.000	150.00	3334	2424.1	1.238	1.031	235.2	4.000	150.00	2938	3599.8	1.250	1.028	254.2	
6.000	100.00	2998	2279.8	1.506	1.144	258.7	6.000	100.00	2660	3725.8	1.527	1.143	282.5	
8.000	75.00	2779	2186.2	1.757	1.211	274.0	8.000	75.00	2478	3611.9	1.788	1.211	299.5	
$r = 1.00$; percent fuel = 5.038; $o/f = 18.88$						$r = 0.40$; percent fuel = 11.70; $o/f = 7.54$								
1.000	600.00	4740	3188.4	-----	-----	-----	1.000	600.00	3795	5318.4	-----	-----	-----	
1.010	594.06	4728	5182.9	4.811	0.095	21.8	1.010	594.06	3784	5312.0	4.772	0.094	23.7	
1.020	588.24	4717	3177.5	5.458	0.134	50.8	1.020	588.24	3775	5308.1	3.411	0.133	33.3	
1.040	576.92	4694	3156.9	2.482	0.188	43.2	1.040	576.92	3759	5283.1	2.463	0.187	45.9	
1.100	545.45	4630	3156.5	1.686	0.292	67.2	1.100	545.45	3710	5257.4	1.855	0.290	72.8	
1.427	420.44	4531	3080.2	1.293	0.402	92.4	1.200	500.00	3637	5202.9	1.286	0.399	100.2	
1.546	391.52	4456	3051.0	1.025	0.555	120.5	1.415	420.22	3500	5035.8	1.083	0.544	158.7	
1.677	357.75	4151	2918.6	0.007	0.667	152.1	1.534	352.03	3637	5030.5	0.601	0.651	161.1	
1.885	323.42	4082	2873.7	1.000	0.721	186.6	1.870	325.38	3586	5005.7	1.007	0.667	155.0	
2.081	291.06	3956	2824.0	1.007	0.775	178.0	2.041	294.02	3213	4893.1	1.007	0.764	192.4	
2.318	258.73	3840	2770.7	1.027	0.828	190.6	2.296	261.56	3125	4829.4	1.027	0.821	206.3	
2.680	226.39	3712	2712.2	1.062	0.886	205.5	2.624	228.85	3028	4759.3	1.064	0.878	220.6	
4.000	150.00	3343	2545.8	1.240	1.030	235.8	4.000	150.00	2759	4552.1	1.253	1.026	258.2	
6.000	100.00	3008	2394.5	1.509	1.143	262.8	6.000	100.00	2481	4717.8	1.532	1.142	287.0	
8.000	75.00	2780	2237.7	1.762	1.211	278.4	8.000	75.00	2512	4284.3	1.795	1.211	304.3	
$r = 0.90$; percent fuel = 5.587; $o/f = 16.96$						$r = 0.30$; percent fuel = 15.027; $o/f = 5.65$								
1.000	600.00	4703	3367.1	-----	-----	-----	1.000	600.00	3388	6577.5	-----	-----	-----	
1.010	594.06	4692	3351.5	4.805	0.095	22.1	1.010	594.06	3380	6570.6	4.787	0.094	24.1	
1.020	588.24	4681	3345.9	3.434	0.134	51.2	1.020	588.24	3372	6564.1	5.407	0.133	33.9	
1.040	576.92	4658	3355.0	2.479	0.188	45.9	1.040	576.92	3357	6551.2	2.460	0.186	47.7	
1.100	545.45	4695	3305.7	1.685	0.292	68.2	1.100	545.45	3315	6514.2	1.653	0.290	74.1	
1.200	500.00	4498	3256.1	1.292	0.402	93.8	1.200	500.00	3250	6257.8	1.285	0.399	102.0	
1.425	421.68	4511	3164.9	1.066	0.554	129.3	1.411	425.23	3151	6155.7	1.069	0.543	158.9	
1.544	386.67	4226	3125.7	0.208	0.610	142.5	1.529	392.54	3074	6106.8	1.029	0.600	153.5	
1.684	356.28	4156	3079.9	1.007	0.685	165.3	1.667	359.82	3013	6054.1	1.007	0.655	157.6	
1.882	323.85	4039	3032.9	1.000	0.719	180.6	1.844	327.11	2947	5998.2	1.000	0.710	181.6	
2.058	291.50	3934	2982.5	1.007	0.773	180.6	2.038	294.47	2776	5957.5	1.007	0.765	198.6	
2.316	269.72	3859	2939.7	1.027	0.814	194.4	2.292	261.56	2767	5955.6	1.007	0.824	203.6	
2.682	236.72	3693	2886.6	1.062	0.864	208.6	2.620	228.46	2712	5798.8	1.064	0.877	224.6	
4.000	150.00	3234	2882.3	1.242	1.030	240.5	4.000	150.00	2453	5583.2	1.254	1.027	254.2	
6.000	100.00	2998	2539.0	1.512	1.143	287.0	6.000	100.00	2224	5398.0	1.534	1.142	292.2	
8.000	75.00	2782	2437.8	1.787	1.211	287.2	8.000	75.00	2073	5275.9	1.798	1.211	309.6	
$r = 0.80$; percent fuel = 6.219; $o/f = 15.08$						$r = 0.20$; percent fuel = 20.865; $o/f = 3.77$								
1.000	600.00	4629	3565.4	-----	-----	-----	1.000	600.00	2756	8275.1	-----	-----	-----	
1.010	594.06	4617	3559.8	4.800	0.095	22.5	1.010	594.06	2750	8266.3	4.775	0.094	24.3	
1.020	588.24	4606	3553.9	3.430	0.134	51.7	1.020	588.24	2742	8259.8	3.412	0.133	34.2	
1.040	576.92	4585	3542.7	2.478	0.188	44.5	1.040	576.92	2712	8248.5	2.464	0.187	48.1	
1.100	545.45	4523	3510.5	1.683	0.292	69.1	1.100	545.45	2677	8208.8	1.656	0.290</td		

TABLE IV. - Concluded. THEORETICAL ROCKET PERFORMANCE AT ASSIGNED PRESSURE RATIOS

FROM 1 TO 8 FOR HYDROGEN AND FLUORINE

(b) Equilibrium composition during isentropic expansion or compression for a chamber pressure of 600 pounds per square inch absolute

Pressure ratio, P_o/P	Pressure, P_o , lb/sq in. abs	Temperature, T , °K	Enthalpy, h , cal/g	Molecular weight, M	Area ratio, ϵ	Thrust coefficient, C_T	Specific impulse, I , lb-sec/lb	Pressure ratio, P_o/P	Pressure, P_o , lb/sq in. abs	Temperature, T , °K	Enthalpy, h , cal/g	Molecular weight, M	Area ratio, ϵ	Thrust coefficient, C_T	Specific impulse, I , lb-sec/lb
$r = 1.20$; percent fuel = 4.235; $o/f = 22.62$															
$r = 0.60$; percent fuel = 8.124; $o/f = 11.31$															
1.000	600.00	4730	2931.6	18.12	—	0.090	21.2	1.000	600.00	4326	4175.5	14.01	—	0.091	23.0
1.010	594.06	4725	2926.5	18.12	4.589	0.090	21.2	1.010	594.06	4320	4167.4	14.02	4.611	0.091	23.0
1.020	588.24	4720	2921.4	18.13	5.281	1.28	23.9	1.020	588.24	4315	4151.4	14.02	3.297	1.28	42.5
1.040	578.92	4710	2911.3	18.14	2.372	1.79	42.0	1.040	576.92	4305	4149.5	14.03	2.584	1.28	45.7
1.100	545.45	4682	2882.5	18.18	1.600	2.79	65.4	1.100	545.45	4276	4115.4	14.05	1.607	2.81	71.1
1.200	500.00	4639	2858.3	18.24	1.250	3.95	90.1	1.200	500.00	4251	4065.2	14.09	1.255	3.87	98.0
1.345	448.01	4583	2781.0	18.32	1.086	4.89	114.5	1.345	445.20	4169	3991.9	14.15	1.083	4.96	125.7
1.457	411.70	4545	2741.4	18.37	1.035	5.84	128.7	1.457	409.11	4128	3945.3	14.18	1.034	5.86	140.9
1.580	377.39	4503	2698.9	18.42	1.008	8.08	142.5	1.580	375.02	4084	3885.3	14.22	1.008	8.14	155.6
1.749	345.08	4455	2653.0	18.48	1.006	8.65	155.7	1.749	340.93	4037	3841.3	14.24	1.000	6.71	170.0
1.943	308.77	4409	2602.4	18.55	1.008	7.22	189.2	1.943	306.83	3985	3782.5	14.31	1.008	7.22	184.4
2.185	274.47	4355	2547.6	18.63	1.032	7.81	182.8	2.185	272.74	3927	3717.9	14.36	1.031	7.86	199.1
2.498	240.15	4294	2486.2	18.71	1.075	8.41	196.9	2.498	238.56	3863	3646.1	14.41	1.075	8.46	214.2
4.000	150.00	4083	2278.4	19.00	1.331	1.018	258.4	4.000	150.00	3845	3407.4	14.80	1.319	1.019	258.2
6.000	100.00	3803	2110.1	18.23	1.682	1.142	267.4	6.000	100.00	3460	3212.5	14.76	1.660	1.141	258.2
8.000	75.00	3774	1996.5	19.38	2.016	1.218	265.5	8.000	75.00	3332	3081.4	14.87	1.985	1.217	308.3
$r = 1.10$; percent fuel = 4.601; $o/f = 20.73$															
$r = 0.50$; percent fuel = 9.893; $o/f = 9.42$															
1.000	600.00	4747	3048.9	17.65	—	0.090	21.5	1.000	600.00	4091	4642.4	12.93	—	—	25.3
1.010	594.06	4742	3045.5	17.68	4.583	0.090	21.5	1.010	594.06	4085	4636.2	12.94	4.621	0.091	25.3
1.020	588.24	4737	3058.3	17.67	3.277	1.27	30.3	1.020	588.24	4080	4630.0	12.94	3.304	1.29	32.9
1.040	576.92	4728	3028.0	17.68	2.588	1.79	42.6	1.040	576.92	4070	4617.9	12.95	2.388	1.81	46.2
1.100	545.45	4701	2989.3	17.72	1.598	2.79	68.3	1.100	545.45	4041	4583.0	12.97	1.610	2.81	71.9
1.345	448.01	4696	2894.6	17.83	1.087	4.87	118.9	1.345	442.55	3985	4485.1	13.00	1.257	3.87	99.1
1.454	412.73	4659	2852.0	17.87	1.074	5.86	134.3	1.454	408.11	4108	4460.2	13.04	1.074	5.86	145.0
1.587	378.68	4636	2809.9	17.96	1.008	6.63	144.2	1.587	374.12	4021	4421.1	13.05	1.008	6.63	172.8
1.745	345.34	4558	2762.4	18.03	1.000	6.65	177.9	1.745	340.71	3980	4366.8	13.15	1.008	7.50	188.9
2.182	274.97	4396	2663.7	18.16	1.032	7.79	185.4	2.182	272.08	3692	4175.2	13.23	1.031	7.88	201.6
2.498	240.50	4282	2590.2	18.25	1.076	8.40	189.8	2.498	238.08	3628	4102.0	13.28	1.075	8.47	216.9
4.000	150.00	4129	2374.4	18.54	1.355	1.018	242.3	4.000	150.00	3411	3840.1	13.44	1.315	1.020	260.6
6.000	100.00	3965	2199.7	18.78	1.693	1.142	271.8	6.000	100.00	3226	3682.0	13.56	1.651	1.141	292.1
8.000	75.00	3852	2081.2	18.95	2.036	1.219	290.2	8.000	75.00	3097	3529.2	13.65	1.970	1.216	311.2
$r = 1.00$; percent fuel = 5.036; $o/f = 18.85$															
$r = 0.40$; percent fuel = 11.710; $o/f = 7.54$															
1.000	600.00	4740	3186.3	17.11	—	0.090	21.8	1.000	600.00	3793	5318.4	11.65	—	—	25.7
1.010	594.06	4735	3177.9	17.12	4.580	0.090	21.8	1.010	594.06	3787	5305.6	11.65	4.631	0.091	25.7
1.020	588.24	4730	3177.5	17.13	3.275	1.27	30.6	1.020	588.24	3782	5305.6	11.66	5.311	1.29	35.4
1.040	576.92	4725	3166.8	17.14	2.368	1.79	45.3	1.040	576.92	3772	5295.1	11.66	2.393	1.81	46.9
1.100	545.45	4694	3136.2	17.18	1.597	2.79	67.5	1.100	545.45	3743	5257.2	11.68	1.615	2.82	75.0
1.345	448.01	4653	3069.3	17.23	1.249	3.84	92.9	1.345	400.77	3698	5202.2	11.71	1.259	3.88	100.6
1.454	412.73	4601	2987.7	17.35	1.035	5.47	132.1	1.454	407.31	3658	5125.8	11.74	1.081	5.02	130.1
1.586	378.34	4524	2942.5	17.41	1.008	6.05	146.3	1.586	372.96	3582	5022.5	11.79	1.008	6.20	160.5
1.744	345.84	4481	2895.6	17.47	1.000	6.65	160.2	1.744	358.06	3505	4985.9	11.82	1.000	6.76	175.1
1.938	309.55	4435	2840.2	17.53	1.008	7.20	174.0	1.938	305.18	3453	4904.3	11.85	1.008	7.33	189.8
2.181	275.16	4384	2761.5	17.60	1.035	7.79	188.2	2.181	272.15	3596	4836.8	11.88	1.031	7.90	204.7
2.492	240.65	4227	2718.0	17.68	1.076	8.39	202.7	2.492	237.44	3531	4768.1	11.92	1.072	8.50	220.1
4.000	150.00	4083	2495.0	17.97	1.337	1.018	246.0	4.000	150.00	3112	4154.6	12.05	1.308	1.020	264.2
6.000	100.00	3973	2312.6	18.21	1.586	1.142	261.1	6.000	100.00	2220	4151.1	12.12	1.586	1.021	295.5
8.000	75.00	3884	2190.1	18.38	2.042	1.219	294.7	8.000	75.00	2784	4180.6	12.16	1.943	1.215	314.6
$r = 0.90$; percent fuel = 5.567; $o/f = 16.98$															
$r = 0.30$; percent fuel = 15.027; $o/f = 5.65$															
1.000	600.00	4703	3357.1	16.49	—	0.090	22.5	1.000	600.00	3588	6377.3	10.08	—	—	24.1
1.010	594.06	4698	3351.6	16.50	4.581	0.090	22.1	1.010	594.06	3582	6370.6	10.08	4.658	0.092	24.1
1.020	588.24	4694	3345.9	16.50	3.276	1.27	31.2	1.020	588.24	3577	6354.1	10.08	5.330	.150	33.8
1.040	576.92	4684	3334.9	16.51	2.369	1.79	43.9	1.040	576.92	3567	6351.1	10.07	2.407	1.82	47.7
1.100	545.45	4657	3303.5	16.55	1.598	2.79	68.3	1.100	545.45	3558	6314.0	10.08	1.621	2.83	74.2
1.345	446.82	4565	3185.5	16.67	1.087	4.57	119.3	1.345	405.38	3223	6170.9	10.12	1.077	5.12	134.0
1.454	412.54	4526	3150.2	16.72	1.035	5.47	134.2	1.454	407.31	3235	6120.6	10.13	1.032	5.71	149.5
1.587	377.16	4488	3103.7	16.77	1.008	6.06	148.5	1.587	369.76	3138	6085.7	10.14	1.008	6.28	164.4
1.745	345.78	4443	3053.3	16.82	1.000	6.63	162.6	1.745	356.18	3089	6008.6	10.18	1.000	6.84	179.1
1.938	309.40	4386	2988.4	16.88	1.000	7.21	176.7	1.938	302.53	3035	5945.5	10.18	1.007	7.40	193.8
2.182	275.03	4344	2938.0	16.95	1.032	7.79	191.0	2.182	268.92	2975	5876.5	10.19	1.030	7.97	208.7
2.493	240.65	4286	2870.6	17.05	1.076	8.3									

TABLE V. - THEORETICAL ROCKET PERFORMANCE AT ASSIGNED PRESSURE RATIOS FROM 10 TO

1500 FOR HYDROGEN AND FLUORINE

(a) Frozen composition during isentropic expansion or compression from a chamber pressure of 600 pounds per square inch absolute

Pressure ratio, P_0/P	Pressure, P_c , lb/sq in. abs	Temperature, T_c , °K	Enthalpy, h_c , cal/g	Area ratio, C_p	Thrust coefficient, C_T	Specific impulse, I_{sp} , lb-sec/1b	Pressure ratio, P_c/P	Pressure, P_c , lb/sq in. abs	Temperature, T_c , °K	Enthalpy, h_c , cal/g	Area ratio, C_p	Thrust coefficient, C_T	Specific impulse, I_{sp} , lb-sec/1b
$r = 1.20$; percent fuel = 4.233; $c/f = 22.62$													
10	60.00	2894	2030.8	1.89	1.258	280.0	10	80.00	2457	3090.8	2.03	1.258	306.8
15	40.00	2325	1921.6	2.52	1.338	296.5	15	40.00	2214	2856.7	2.58	1.354	325.4
20	30.00	2145	1851.1	3.00	1.377	306.8	20	30.00	2063	2869.7	3.09	1.381	336.8
30	20.00	1917	1780.8	5.68	1.454	319.2	30	20.00	1844	2757.7	1.35	1.439	351.0
40	15.00	1767	1702.7	4.85	1.469	327.0	40	15.00	1707	2683.5	4.80	1.478	359.9
50	10.00	1574	1628.5	6.01	1.515	336.7	60	10.00	1525	2592.5	6.25	1.521	370.9
60	7.50	1477	1554.9	7.49	1.542	346.8	80	7.50	1469	2526.7	7.38	1.530	377.9
100	4.00	1355	1456.8	8.37	1.559	357.4	100	4.00	1326	2481.1	8.14	1.539	386.9
150	2.00	1202	1489.8	10.91	1.591	354.2	150	4.00	1181	2417.2	11.48	1.603	390.9
200	1.50	1102	1485.5	13.17	1.611	358.6	200	3.00	1086	2371.0	15.88	1.624	396.0
300	2.00	974	1407.4	17.20	1.636	384.2	300	2.00	965	2312.0	18.20	1.650	402.5
400	1.50	892	1378.0	20.79	1.652	387.7	400	1.50	887	2274.5	22.07	1.687	406.5
600	1.00	787	1340.7	27.19	1.671	372.1	600	1.00	768	2226.3	28.98	1.688	411.5
800	.75	720	1317.0	32.92	1.684	374.8	800	.75	721	2195.3	36.18	1.701	414.9
1000	.60	671	1289.8	38.19	1.693	378.8	1000	.60	674	2173.5	40.81	1.711	417.2
1500	.40	592	1271.9	50.08	1.707	380.0	1500	.45	597	2137.0	53.85	1.728	421.0
$r = 1.10$; percent fuel = 4.601; $c/f = 20.73$													
10	60.00	2618	2118.5	1.99	1.258	284.5	10	60.00	2341	3529.3	2.03	1.259	311.2
15	40.00	2348	2005.2	2.53	1.338	303.5	15	40.00	2111	3390.8	2.59	1.355	350.0
20	30.00	2171	1935.1	3.02	1.378	311.7	20	30.00	1960	3300.8	3.10	1.382	341.7
30	20.00	1842	1858.5	3.68	1.435	324.6	30	20.00	1762	3185.0	4.01	1.440	356.1
40	15.00	1711	1814.4	4.64	1.471	336.8	40	15.00	1632	3110.0	4.65	1.477	365.2
60	10.00	1595	1700.7	6.06	1.514	342.5	60	10.00	1525	3050.0	5.50	1.521	374.5
80	7.50	1469	1651.1	7.30	1.542	348.8	80	7.50	1520	2915.6	7.61	1.551	383.8
100	5.00	1377	1615.3	8.44	1.561	353.2	100	5.00	1289	2806.7	8.83	1.572	384.8
150	4.00	1222	1585.1	11.01	1.592	360.4	150	4.00	1151	2632.0	11.58	1.605	398.9
200	3.00	1121	1518.2	13.30	1.613	365.0	200	3.00	1042	2784.0	14.01	1.626	402.1
300	2.00	992	1470.0	17.58	1.636	370.5	300	2.00	928	2728.7	18.39	1.653	408.7
400	1.50	898	1458.3	21.02	1.654	374.2	400	1.50	832	2683.5	22.31	1.670	412.9
600	1.00	802	1421.4	25.74	1.674	378.5	600	1.00	756	2628.6	28.53	1.681	416.1
800	.75	754	1375.4	33.32	1.687	381.8	800	.75	694	2601.4	35.83	1.704	421.5
1000	.60	685	1357.6	54.67	1.696	385.8	1000	.60	550	2674.4	41.46	1.714	423.8
1500	.40	594	1282.2	50.75	1.710	386.9	1500	.45	576	2540.2	54.82	1.730	427.7
$r = 1.00$; percent fuel = 5.058; $c/f = 18.83$													
10	60.00	2550	2027.5	2.00	1.258	289.1	10	60.00	2187	4168.7	2.04	1.260	316.3
15	40.00	2261	2014.1	2.54	1.338	303.5	15	40.00	1974	3951.5	3.12	1.355	338.5
20	30.00	2184	2034.3	3.03	1.379	316.9	20	30.00	1854	3935.1	3.12	1.385	345.1
30	20.00	1985	1936.9	3.91	1.436	330.0	30	20.00	1680	3811.1	4.04	1.441	362.1
40	15.00	1805	1874.1	4.69	1.471	338.2	40	15.00	1529	3733.2	4.86	1.478	371.4
60	10.00	1611	1792.5	6.10	1.518	348.3	60	10.00	1571	3533.0	6.34	1.524	383.0
80	7.50	1485	1742.2	7.35	1.543	354.7	80	7.50	1267	3468.3	7.87	1.555	390.2
100	6.00	1391	1704.9	8.51	1.563	359.3	100	6.00	1191	3521.6	8.90	1.574	398.4
150	4.00	1225	1683.2	11.13	1.595	364.7	150	4.00	1083	3443.7	11.86	1.608	405.9
200	3.00	1154	1654.1	13.61	1.614	369.1	200	3.00	950	3455.1	13.11	1.629	409.2
300	2.00	1004	1653.3	15.58	1.641	377.2	300	2.00	872	3224.6	18.58	1.656	415.0
400	1.50	921	1821.2	21.25	1.657	380.9	400	1.50	802	3286.6	22.86	1.673	420.3
600	1.00	814	1840.4	27.65	1.677	385.5	600	1.00	713	3258.2	28.69	1.684	425.6
800	.75	745	1845.4	35.71	1.690	388.4	800	.75	656	3208.7	55.11	1.706	429.1
1000	.60	701	1841.5	54.68	1.692	394.4	1000	.60	592	3255.1	56.31	1.708	437.2
1500	.40	619	1809.7	51.97	1.717	400.3	1500	.40	545	3138.4	55.48	1.733	438.5
$r = 0.90$; percent fuel = 5.887; $c/f = 16.88$													
10	60.00	2525	2555.1	2.01	1.258	293.8	10	60.00	1962	5185.0	2.05	1.259	322.1
15	40.00	2358	2245.5	2.55	1.338	311.5	15	40.00	1771	6035.6	2.61	1.355	342.7
20	30.00	2185	2184.5	3.04	1.379	322.8	20	30.00	1646	4958.6	3.13	1.383	353.8
30	20.00	1968	1936.9	3.91	1.436	340.5	30	20.00	1481	4813.4	4.05	1.442	368.9
40	15.00	1807	1998.6	4.72	1.472	343.5	40	15.00	1372	4735.2	4.87	1.479	378.5
60	10.00	1614	1918.1	6.10	1.518	354.2	60	10.00	1230	4628.2	6.38	1.525	390.1
80	7.50	1505	1874.4	7.49	1.545	359.4	80	7.50	1177	4557.5	7.81	1.554	397.5
100	6.00	1422	1822.6	8.57	1.568	364.4	100	6.00	1069	4432.5	8.82	1.584	409.8
150	4.00	1240	1783.8	11.20	1.597	375.0	150	4.00	855	4431.3	11.89	1.608	411.5
200	3.00	1140	1717.1	13.54	1.618	377.8	200	3.00	890	4379.2	24.18	1.630	417.0
300	2.00	1010	1864.8	17.72	1.643	383.5	300	2.00	794	4312.6	18.84	1.657	425.9
400	1.50	928	1831.1	21.46	1.660	397.5	400	1.50	722	4289.8	22.67	1.674	428.2
600	1.00	819	1888.5	28.12	1.680	392.3	600	1.00	604	4216.2	29.67	1.695	433.7
800	.75	750	1856.5	54.68	1.692	404.4	800	.75	592	4252.1	56.31	1.708	437.2
1000	.60	701	1841.5	54.68	1.705	404.3	1000	.60	495	4154.0	55.39	1.718	438.5
1500	.40	619	1809.7	51.97	1.720	407.8	1500	.40	494	4121.9	56.03	1.732	443.5
$r = 0.80$; percent fuel = 6.219; $c/f = 15.08$													
10	60.00	2557	2416.5	2.01	1.258	298.4	10	60.00	1566	7054.5	2.05	1.258	324.5
15	40.00	2385	2245.5	2.58	1.338	312.9	15	40.00	1410	6914.4	2.59	1.354	343.5
20	30.00	2144	2184.5	3.08	1.379	322.8	20	30.00	1308	6801.1	3.05	1.383	358.8
30	20.00	1940	2250.1	3.91	1.436	342.5	30	20.00	1201	6709.5	3.59	1.399	369.5
40	15.00	1807	1998.6	4.72	1.472	343.5	40	15.00	1045	6661.0	4.60	1.476	380.3
60	10.00	1603	2075.7	5.18	1.518	350.0	60	10.00	970	6507.3	6.24	1.521	392.0
80	7.50	1478	2019.9	7.48	1.546	368.7	80	7.50	896	6440.5	7.54	1.550	398.9
100	6.00	1388	1979.7	8.63	1.568	372.4	100	6.00	842	6392.2	8.78	1.570	404.5
150	4.00	1224	1912.7	11.29	1.599	378.2	150	4.00</td					

TABLE V. - Continued. THEORETICAL ROCKET PERFORMANCE AT ASSIGNED PRESSURE RATIOS FROM 10 TO 1500 FOR HYDROGEN AND FLUORINE

(b) Equilibrium composition during isentropic expansion or compression from a chamber pressure of 600 pounds per square inch absolute

Pres- sure ratio, P_o/P	Pres- sure, P , lb/sq in. abs	Tem- pera- ture, T , °K	En- thalpy, h , cal/g	Molec- ular weight, M	Area ratio, ϵ	Thrust co- effi- cient, C_F	Specific impulse, I , lb-sec lb	Pres- sure ratio, P_o/P	Pres- sure, P , lb/sq in. abs	Tem- pera- ture, T , °K	En- thalpy, h , cal/g	Molec- ular weight, M	Area ratio, ϵ	Thrust co- effi- cient, C_F	Specific impulse, I , lb-sec lb	
$r = 1.20$; percent fuel = 4.253; o/f = 22.62																
10	60.00	3871	1911.6	18.49	2.35	1.272	297.9	10	60.00	3727	2856.1	17.79	2.37	1.274	312.3	
15	40.00	5470	1754.6	18.66	3.07	1.351	318.7	15	40.00	3575	2071.8	18.00	3.14	1.364	354.4	
20	30.00	5311	1688.2	18.75	3.73	1.417	351.6	20	30.00	3484	1980.4	18.14	3.86	1.422	348.6	
30	20.00	5058	1536.4	18.82	4.80	1.488	348.4	30	20.00	3508	1810.8	18.32	5.21	1.498	368.8	
40	15.00	2861	1451.1	18.85	5.94	1.555	358.9	40	15.00	3198	1709.6	18.44	6.46	1.545	378.6	
60	10.00	2591	1340.4	18.84	7.76	1.588	372.1	60	10.00	3054	1574.0	18.60	8.76	1.607	393.9	
80	7.50	2410	1269.4	18.84	9.43	1.625	380.4	80	7.50	2915	1482.8	18.70	10.89	1.647	405.8	
100	6.00	2277	1218.0	18.84	10.97	1.650	386.4	100	6.00	2820	1415.0	18.77	12.89	1.677	411.1	
150	4.00	2051	1128.2	18.84	14.48	1.692	398.1	150	4.00	2642	1298.0	18.87	17.50	1.727	425.5	
200	3.00	1903	1071.3	18.84	17.60	1.718	402.3	200	3.00	2612	1220.1	18.93	21.71	1.759	431.2	
300	2.00	1709	998.0	18.84	23.28	1.752	410.2	300	2.00	2525	1117.3	18.00	28.33	1.801	441.5	
400	1.50	1582	850.6	18.84	28.36	1.775	415.2	400	1.50	2190	1048.4	18.02	38.24	1.828	448.1	
600	1.00	1416	889.8	18.84	37.50	1.800	421.5	600	1.00	2000	960.8	18.05	48.66	1.865	458.8	
800	.75	1310	860.5	18.85	45.79	1.817	428.8	800	.75	1889	902.7	18.08	58.88	1.885	462.1	
1000	.60	1235	822.1	18.87	55.55	1.850	428.4	1000	.60	1770	860.4	19.06	70.28	1.901	466.1	
1500	.40	1117	774.6	18.94	71.63	1.860	433.2	1500	.40	1800	789.2	18.08	93.93	1.928	472.7	
$r = 1.10$; percent fuel = 4.801; o/f = 20.73																
10	80.00	3766	1992.4	19.08	2.37	1.274	303.2	10	60.00	3603	2417.9	18.95	2.34	1.275	316.0	
15	40.00	3609	1857.6	19.30	3.14	1.384	324.6	15	40.00	3434	2251.6	17.14	3.10	1.382	338.1	
20	30.00	3497	1732.8	19.45	3.86	1.422	338.4	20	30.00	3315	2139.4	17.28	3.80	1.419	352.3	
30	20.00	3335	1581.9	19.85	5.20	1.496	356.1	50	20.00	3143	1989.3	17.42	5.09	1.491	370.3	
40	15.00	3208	1496.9	19.74	6.42	1.544	367.5	40	15.00	3026	1868.3	17.55	6.29	1.538	382.0	
60	10.00	3003	1370.5	19.85	8.63	1.606	382.2	80	10.00	2858	1753.7	17.66	8.50	1.598	397.0	
80	7.50	2839	1286.4	19.89	10.59	1.648	391.8	80	7.50	2732	1683.5	17.75	10.54	1.638	406.8	
100	6.00	2705	1224.8	19.91	12.38	1.674	398.4	100	6.00	2635	1598.8	17.81	12.45	1.667	415.8	
150	4.00	2455	1120.3	19.92	16.40	1.722	408.6	150	4.00	2456	1481.7	17.89	18.88	1.715	425.8	
200	3.00	2288	1058.3	19.92	20.02	1.752	416.8	200	3.00	2326	1404.6	17.94	20.82	1.746	433.5	
300	2.00	2068	964.3	19.92	26.57	1.790	426.9	300	2.00	2158	1305.2	17.98	26.02	1.786	443.5	
400	1.50	1923	907.0	19.92	32.50	1.814	431.7	400	1.50	2006	1239.4	17.99	34.51	1.812	449.9	
600	1.00	1732	833.1	19.92	43.18	1.845	439.1	600	1.00	1823	1153.7	18.00	46.18	1.845	458.1	
800	.75	1607	785.2	19.92	52.84	1.865	443.8	800	.75	1898	1097.8	18.01	58.71	1.866	463.4	
1000	.60	1515	750.5	19.92	61.78	1.879	447.2	1000	.60	1506	1057.1	18.01	66.46	1.881	467.2	
1500	.40	1359	692.4	19.92	82.11	1.903	452.8	1500	.40	1448	988.8	18.01	88.69	1.807	473.5	
$r = 1.00$; percent fuel = 5.058; o/f = 18.85																
10	60.00	5782	2088.2	18.51	2.37	1.278	506.0	10	60.00	3452	2659.6	18.01	2.31	1.271	318.0	
15	40.00	5636	1837.7	18.73	3.16	1.365	528.9	15	40.00	3258	2492.2	16.18	3.06	1.358	341.1	
20	30.00	5534	1828.8	18.88	3.89	1.423	543.9	20	30.00	3158	2379.5	16.28	5.74	1.415	355.1	
30	20.00	5392	1881.8	19.09	5.27	1.488	562.1	30	20.00	2964	2229.3	16.42	5.00	1.486	373.1	
40	15.00	5292	1582.1	19.23	6.55	1.547	573.9	40	15.00	2842	2128.5	16.51	6.18	1.533	394.7	
60	10.00	5151	1445.9	19.41	8.95	1.611	588.4	60	10.00	2668	1994.6	16.62	8.30	1.592	398.5	
7.50	5048	1355.4	19.53	11.19	1.653	599.4	80	7.50	2542	1805.1	16.89	10.28	1.630	409.2		
100	6.00	2957	1287.8	19.82	13.31	1.685	406.6	100	6.00	2443	1859.0	16.75	12.09	1.658	416.1	
150	4.00	2813	1170.5	19.76	18.24	1.754	419.0	150	4.00	2258	1725.9	16.78	16.25	1.704	427.8	
200	3.00	2698	1080.7	19.83	22.78	1.768	427.2	200	3.00	2126	1851.3	16.80	20.02	1.734	435.5	
300	2.00	2524	984.9	19.92	31.06	1.812	437.8	300	2.00	1940	1553.9	16.82	28.78	1.773	444.8	
400	1.50	2392	914.4	19.96	38.58	1.841	444.8	400	1.50	1811	1490.2	16.83	32.87	1.797	451.1	
600	1.00	2198	821.8	19.99	52.01	1.878	453.8	600	1.00	1858	1407.7	16.85	45.85	1.829	459.0	
800	.75	2059	761.0	20.00	64.12	1.902	459.6	800	.75	1523	1354.0	16.83	53.73	1.849	464.1	
1000	.60	1854	716.5	20.00	75.54	1.919	463.8	1000	.60	1458	1318.0	16.83	62.91	1.865	487.7	
1500	.40	1770	641.6	20.01	100.84	1.948	470.7	1500	.40	1293	1248.7	16.83	83.77	1.888	473.8	

TABLE V. - Concluded. THEORETICAL ROCKET PERFORMANCE AT ASSIGNED PRESSURE RATIOS FROM 10 TO 1500 FOR HYDROGEN AND FLUORINE
 (b) Concluded. Equilibrium composition during isentropic expansion or compression from a chamber pressure of
 600 pounds per square inch absolute

Pres- sure ratio, P_c/P	Pres- sure, P, lb/sq in. abs	Tem- pera- ture, T, °K	En- thalpy, h, cal/g	Mole- cular weight, M	Area ratio, e	Thrust co- effi- cient, C_F	Specific impulse, I, lb-sec lb	Pres- sure ratio, P_c/P	Pres- sure, P, lb/sq in. abs	Tem- pera- ture, T, °K	En- thalpy, h, cal/g	Mole- cular weight, M	Area ratio, e	Thrust co- effi- cient, C_F	Specific impulse, I, lb-sec lb
$r = 0.60$; percent fuel = 8.124; o/f = 11.31															
10	60.00	3235	2983.8	14.95	2.29	1.270	321.7	10	60.00	2214	5123.2	10.31	2.15	1.261	330.3
15	40.00	3059	2815.0	15.09	3.02	1.357	343.8	15	40.00	2017	4958.0	10.32	2.75	1.342	351.4
20	30.00	2934	2701.8	15.17	3.69	1.412	357.9	20	30.00	1863	4849.9	10.32	3.30	1.382	364.6
30	20.00	2758	2551.2	15.28	4.92	1.483	375.7	30	20.00	1704	4710.0	10.32	4.29	1.454	380.9
40	15.00	2632	2450.6	15.35	6.05	1.528	387.2	40	15.00	1585	4618.9	10.32	5.18	1.493	391.2
60	10.00	2450	2317.4	15.42	8.10	1.586	401.9	60	10.00	1428	4501.4	10.32	8.78	1.542	404.0
80	7.50	2318	2228.1	15.45	9.96	1.624	411.3	80	7.50	1324	4425.2	10.32	9.22	1.574	412.1
100	6.00	2214	2164.2	15.47	11.68	1.650	418.1	100	6.00	1248	4370.0	10.32	9.55	1.596	417.9
150	4.00	2026	2053.8	15.50	15.59	1.695	429.5	150	4.00	1119	4277.7	10.32	12.56	1.652	427.4
200	3.00	1895	1981.5	15.50	19.10	1.724	436.7	200	3.00	1035	4218.1	10.32	15.27	1.655	435.5
300	2.00	1717	1887.7	15.51	25.42	1.760	446.0	300	2.00	926	4141.6	10.32	20.13	1.684	441.1
400	1.50	1598	1826.6	15.51	31.12	1.784	451.8	400	1.50	854	4082.3	10.32	24.50	1.702	445.9
600	1.00	1440	1747.8	15.51	41.38	1.813	459.4	600	1.00	762	4029.3	10.32	32.55	1.726	452.0
800	.75	1336	1698.6	15.51	50.65	1.832	464.2	800	.75	703	3988.8	10.32	39.43	1.741	455.9
1000	.60	1259	1659.5	15.51	59.23	1.846	467.7	1000	.60	680	3959.5	10.32	45.99	1.751	458.7
1500	.40	1129	1597.6	15.51	78.72	1.869	473.4	1500	.40	588	3910.9	10.32	80.87	1.769	463.3
$r = 0.50$; percent fuel = 9.583; o/f = 9.42															
10	60.00	2997	3450.4	13.71	2.27	1.269	324.7	10	60.00	1607	7047.9	8.01	2.04	1.257	326.5
15	40.00	2815	3260.2	13.80	2.98	1.355	346.8	15	40.00	1448	6894.5	8.01	2.60	1.353	346.3
20	30.00	2684	3146.6	13.86	3.63	1.410	360.8	20	30.00	1345	6795.0	8.01	3.11	1.380	358.6
30	20.00	2498	2996.3	13.93	4.80	1.479	378.5	30	20.00	1206	6666.9	8.01	4.02	1.459	373.8
40	15.00	2363	2896.6	13.96	5.87	1.523	389.8	40	15.00	1116	6584.3	8.01	4.83	1.475	383.5
80	10.00	2172	2786.9	13.99	7.78	1.579	404.1	80	10.00	999	6478.0	8.01	6.30	1.521	395.2
80	7.50	2057	2679.9	14.00	9.52	1.615	413.2	80	7.50	925	6409.5	8.01	7.61	1.550	402.7
100	6.00	1934	2617.0	14.00	11.11	1.640	419.8	100	6.00	867	6360.0	8.01	8.82	1.570	408.0
150	4.00	1763	2511.1	14.01	14.76	1.683	430.8	150	4.00	774	6227.4	8.01	11.56	1.604	418.7
200	3.00	1632	2442.0	14.01	17.98	1.710	437.6	200	3.00	713	6224.6	8.01	14.05	1.625	422.2
300	2.00	1472	2352.8	14.01	23.85	1.744	446.3	300	2.00	636	6156.8	8.01	18.46	1.652	429.1
400	1.50	1365	2295.0	14.01	29.14	1.786	452.0	400	1.50	586	6113.2	8.01	22.45	1.688	433.5
600	1.00	1226	2220.5	14.01	58.65	1.794	459.1	600	1.00	522	6057.6	8.01	29.63	1.690	439.1
800	.75	1135	2172.4	14.01	47.25	1.812	463.8	800	.75	481	6021.8	8.01	36.12	1.703	442.6
1000	.60	1068	2137.5	14.01	55.17	1.824	468.9	1000	.60	451	5996.0	8.01	42.13	1.713	446.1
1500	.40	856	2079.4	14.01	73.18	1.845	472.2	1500	.40	402	5953.1	8.01	55.78	1.729	449.3
$r = 0.40$; percent fuel = 11.710; o/f = 7.54															
10	60.00	2677	4081.3	12.19	2.23	1.267	328.1	10	60.00	1261	8751.0	6.71	2.00	1.257	319.1
15	40.00	2482	3911.2	12.24	2.90	1.351	349.9	15	40.00	1131	8607.5	6.71	2.55	1.352	338.1
20	30.00	2342	3798.7	12.26	3.51	1.404	363.6	20	30.00	1045	8514.9	6.71	3.05	1.378	349.8
30	20.00	2146	3651.4	12.28	4.59	1.470	380.9	50	20.00	935	8396.2	6.71	3.91	1.435	364.5
40	15.00	2009	3554.7	12.29	5.57	1.512	391.7	40	15.00	865	8319.6	6.71	4.69	1.470	375.3
60	10.00	1824	3429.2	12.30	7.33	1.585	405.4	60	10.00	770	8221.7	6.71	6.10	1.515	384.6
80	7.50	1699	3347.3	12.30	8.91	1.599	414.1	80	7.50	710	8158.6	6.71	7.36	1.542	391.6
100	6.00	1606	3287.7	12.30	10.37	1.623	420.4	100	6.00	667	8113.1	6.71	8.53	1.562	396.6
150	4.00	1448	3187.7	12.30	13.69	1.662	430.6	150	4.00	594	8037.5	6.71	11.17	1.594	404.9
200	3.00	1343	3122.9	12.30	16.68	1.687	437.1	200	3.00	548	7988.8	6.71	13.55	1.615	410.0
300	2.00	1206	3059.5	12.30	22.05	1.719	445.3	500	2.00	488	7926.7	6.71	17.85	1.641	416.6
400	1.50	1116	2985.5	12.30	26.89	1.739	450.5	400	1.50	450	7888.8	6.71	21.69	1.657	420.7
600	1.00	999	2916.4	12.30	35.58	1.765	457.2	600	1.00	401	7835.8	6.71	28.63	1.678	426.0
800	.75	922	2871.7	12.30	43.40	1.781	461.4	800	.75	369	7803.0	6.71	34.80	1.691	429.3
1000	.60	887	2839.5	12.30	50.65	1.793	464.4	1000	.80	346	7778.5	6.71	40.70	1.700	431.7
1500	.40	774	2765.8	12.30	67.08	1.812	469.4	1500	.40	308	7740.1	6.71	63.86	1.716	435.6

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TABLE VI. - THEORETICAL ROCKET PERFORMANCE FOR COMPLETE EXPANSION TO
EXIT PRESSURE OF 1 ATMOSPHERE FOR HYDROGEN AND FLUORINE AT A CHAMBER
PRESSURE OF 600 POUNDS PER SQUARE INCH ABSOLUTE

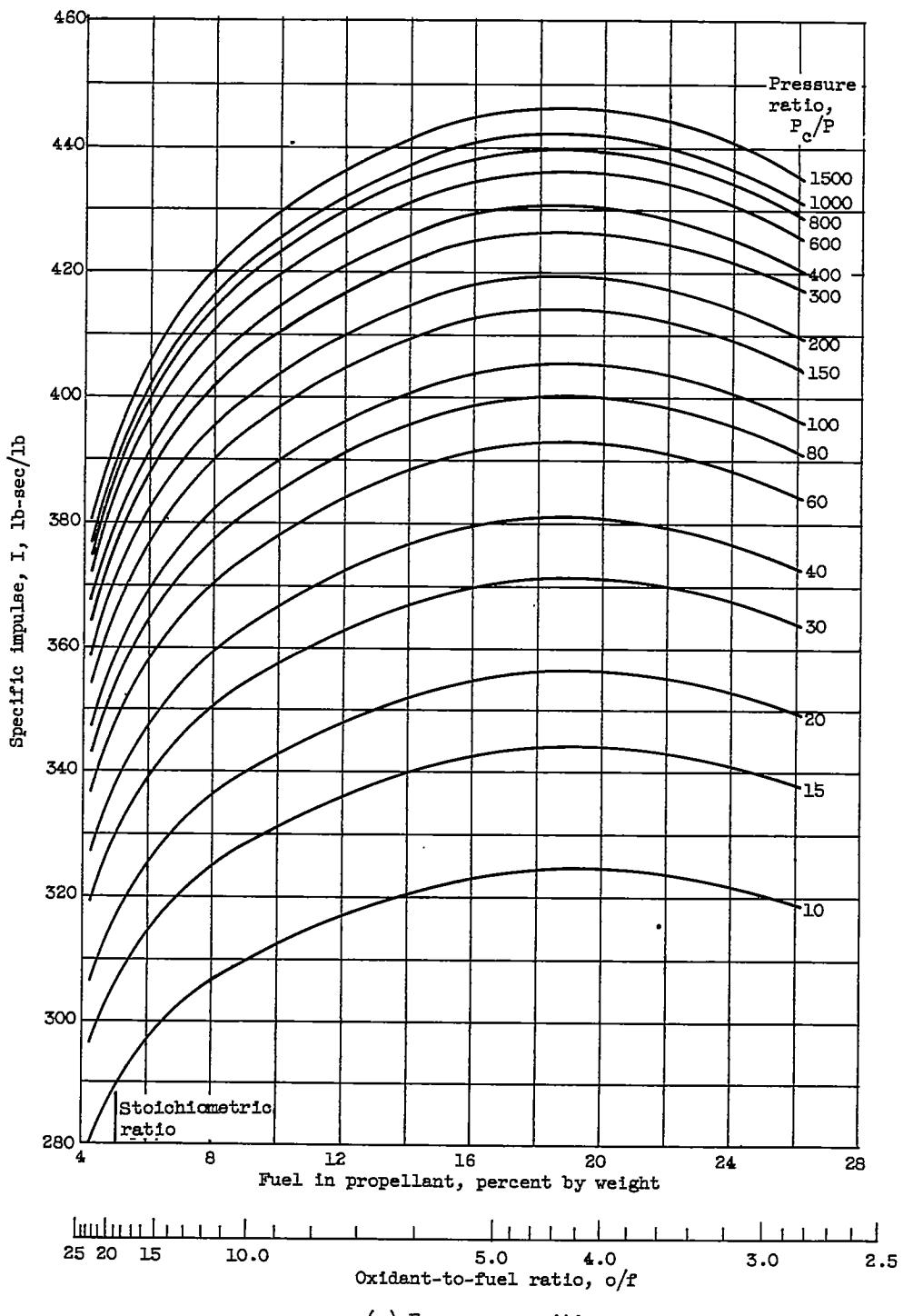
Equiva- lence ratio, $\frac{F}{H}$	Per- cent fuel by weight	Oxidant- to-fuel weight ratio, o/f	Combus- tion temper- ature, T_c , °K	Exit tem- pera- ture, T_e , °K	Char- acter- istic veloc- ity, c^* , ft/sec	Area ratio, ϵ	Thrust co- effi- cient, C_F	Spe- cific im- pulse, I , lb-sec lb	Molec- ular weight, M_e
Frozen composition									
1.20	4.234	22.62	4730	1757	7163	4.69	1.471	327.5	18.12
1.10	4.601	20.73	4747	1781	7278	4.73	1.472	333.1	17.65
1.00	5.038	18.85	4740	1795	7396	4.75	1.474	338.7	17.11
.90	5.567	16.96	4703	1797	7513	4.78	1.475	344.4	16.49
.80	6.219	15.08	4629	1784	7630	4.81	1.476	350.0	15.77
.70	7.045	13.19	4505	1751	7741	4.84	1.477	355.3	14.95
.60	8.124	11.31	4326	1698	7846	4.87	1.478	360.4	14.01
.50	9.593	9.42	4090	1623	7955	4.90	1.479	365.8	12.93
.40	11.710	7.54	3793	1521	8084	4.93	1.481	372.0	11.65
.30	15.027	5.65	3388	1365	8232	4.94	1.481	379.0	10.06
.20	20.965	3.77	2736	1079	8292	4.86	1.478	380.9	7.98
.15	26.128	2.83	2242	855	8158	4.75	1.473	373.4	6.71
Equilibrium composition									
1.20	4.234	22.62	4730	2847	7533	6.02	1.536	359.6	19.83
1.10	4.601	20.73	4747	3197	7656	6.52	1.548	368.3	19.75
1.00	5.038	18.85	4740	3285	7774	6.66	1.551	374.7	19.24
.90	5.567	16.96	4703	3188	7887	6.56	1.548	379.4	18.45
.80	6.219	15.08	4629	3017	7989	6.39	1.542	382.8	17.54
.70	7.045	13.19	4505	2833	8075	6.26	1.536	385.5	16.52
.60	8.124	11.31	4326	2620	8151	6.13	1.531	388.0	15.35
.50	9.593	9.42	4090	2354	8234	5.96	1.526	390.5	13.96
.40	11.710	7.54	3793	2000	8334	5.65	1.515	392.5	12.29
.30	15.027	5.65	3388	1577	8427	5.25	1.496	391.8	10.32
.20	20.965	3.77	2736	1110	8360	4.90	1.478	383.9	8.01
.15	26.128	2.83	2242	858	8169	4.74	1.473	373.9	6.71

TABLE VII. - EQUILIBRIUM COMPOSITION OF PRODUCTS OF REACTION AT ASSIGNED TEMPERATURES
FOR HYDROGEN AND FLUORINE

Isentropic expansion or compression from combustion conditions; chamber pressure, 600 lb/sq in. abs.												
Mole fraction at temperature T												
$r = 1.20$; percent fuel = 4.235; $\sigma/T = 22.62$												
T, °K	1200	1600	2000	2400	2800	3200	3600	4000	4400	b ₄₇₅₀	4800	
F	0.16259	0.16645	0.16862	0.18885	0.16883	0.15901	0.17882	0.20112	0.22759	0.24983	0.25449	
F ₂	.00222	.00012	.00002	.00001	.00001	—	.00001	.00001	.00001	.00003	.00003	
H	—	—	—	—	—	—	—	—	—	.07593	.07987	
H ₂	.63519	.83343	.83355	.83353	.83286	.82833	.80616	.78197	.70818	.66334	.65398	
$r = 1.10$; percent fuel = 4.601; $\sigma/T = 20.73$												
T, °K	1200	1600	2000	2400	2800	3200	3600	4000	4400	b ₄₇₄₇	4800	
F	0.08029	0.08086	0.09080	0.09095	0.08169	0.09946	0.12208	0.15275	0.18462	0.21107	0.21494	
F ₂	.00052	.00002	—	—	—	—	—	—	—	.00001	.00002	
H	—	—	—	—	.00002	.00077	.00778	.02882	.05157	.08672	.09364	
H ₂	—	—	—	—	.00004	.00078	.00355	.00784	.01286	.01693	.01754	
HF	.90938	.90911	.90899	.90905	.90750	.89198	.84754	.78783	.72818	.67529	.66785	
$r = 1.00$; percent fuel = 5.058; $\sigma/T = 18.85$												
T, °K	1200	1600	2000	2400	2800	3200	3600	4000	4400	b ₄₇₄₀	4800	
F	—	—	0.00001	0.00039	0.00348	0.01551	0.05966	0.07254	0.10811	0.14285	0.17051	0.17518
F ₂	—	—	—	—	—	—	—	—	—	.00001	.00001	
H	—	—	—	—	.00009	.00154	.00898	.02607	.04980	.07528	.09866	.11870
H ₂	—	—	—	—	.00001	.00015	.00317	.00879	.01357	.01642	.02180	.02592
HF	1.00000	.99998	.99957	.99401	.97256	.92748	.86628	.80019	.75889	.68486	.67626	
$r = 0.90$; percent fuel = 5.567; $\sigma/T = 16.98$												
T, °K	1200	1600	2000	2400	2800	3200	3600	4000	4400	b ₄₇₀₅	4800	
F	—	—	—	0.00002	0.00038	0.00537	0.01517	0.03947	0.07210	0.10457	0.13281	0.13664
F ₂	—	—	—	—	—	—	—	—	—	.00001	.00001	
H	—	—	—	—	.00008	.00142	.00871	.02826	.05055	.07651	.10056	.12454
H ₂	—	—	—	—	.00001	.00159	.04823	.04041	.03832	.03137	.03521	.03773
HF	.94737	.94733	.94687	.94259	.92995	.86101	.85325	.79461	.75456	.69053	.67710	
$r = 0.80$; percent fuel = 6.219; $\sigma/T = 15.08$												
T, °K	1200	1600	2000	2400	2800	3200	3600	4000	4400	b ₄₆₂₈	4800	
F	—	—	—	—	0.00001	0.00020	0.00167	0.00756	0.02175	0.04457	0.07232	0.08891
F ₂	—	—	—	—	—	—	—	—	—	.00001	.00001	
H	—	—	—	—	.00008	.00170	.01050	.02320	.05352	.09485	.12286	.14712
H ₂	—	—	—	—	.00001	.00113	.01057	.02591	.05903	.08281	.08152	.10542
HF	.88889	.88885	.88812	.88594	.87212	.84982	.81527	.76886	.71804	.68961	.68783	
$r = 0.70$; percent fuel = 7.045; $\sigma/T = 13.19$												
T, °K	900	1200	1600	2000	2400	2800	3200	3600	4000	b ₄₅₀₅	4800	
F	—	—	—	—	—	0.00011	0.00096	0.00429	0.01258	0.02732	0.04762	0.05356
F ₂	—	—	—	—	—	—	—	—	—	.00001	.00001	
H	—	—	—	—	—	0.00009	0.00172	.01074	.03560	.06789	.10398	.13659
H ₂	—	—	—	—	—	.00008	.00160	.01003	.03198	.06600	.10452	.13844
HF	0.17847	0.17647	0.17642	0.17546	0.17020	0.15710	0.13848	0.12050	0.10757	.09970	.08945	.09810
	.82353	.82353	.82281	.81895	.78965	.76295	.72871	.70084	.67458	.65026	.64652	
$r = 0.60$; percent fuel = 8.124; $\sigma/T = 11.31$												
T, °K	900	1200	1600	2000	2400	2800	3200	3600	4000	b ₄₃₂₆	4400	
F	—	—	—	—	—	0.00007	0.00057	0.00253	0.00745	0.01657	0.02728	0.03010
F ₂	—	—	—	—	—	—	—	—	—	.00001	.00001	
H	—	—	—	—	—	0.00008	0.00060	.00103	.03198	.06500	.10452	.14058
H ₂	—	—	—	—	—	.00006	.00048	.00095	.02528	.05205	.09344	.13461
HF	.75000	.75000	.74997	.74940	.74615	.71722	.72177	.70177	.68759	.67287	.66884	.67784
$r = 0.50$; percent fuel = 9.593; $\sigma/T = 9.42$												
T, °K	900	1200	1600	2000	2400	2800	3200	3600	4000	b ₄₀₉₀	4400	
F	—	—	—	—	—	—	0.00004	0.00035	0.00146	0.00434	0.00978	0.01145
F ₂	—	—	—	—	—	—	—	—	—	.00001	.00001	
H	—	—	—	—	—	0.00007	0.00156	.00884	.02818	.05988	.09743	.13461
H ₂	—	—	—	—	—	.00005	.00029	.00074	.02125	.05303	.09301	.14256
HF	0.35353	0.35353	.35329	.35323	.32759	.31485	.29390	.26983	.24885	.24210	.22745	.22745
$r = 0.40$; percent fuel = 11.710; $\sigma/T = 7.54$												
T, °K	900	1200	1600	2000	2400	2800	3200	3600	4000	b ₃₇₉₃	4400	
F	—	—	—	—	—	—	0.00002	0.00017	0.00079	0.00237	0.00584	0.00544
F ₂	—	—	—	—	—	—	—	—	—	.00001	.00001	
H	—	—	—	—	—	—	0.00006	0.00018	.00081	.02279	.05008	.08423
H ₂	—	—	—	—	—	—	.00005	.00015	.00474	.01235	.03930	.05714
HF	0.42857	0.42857	0.42853	0.42781	0.42271	0.41235	.39303	.36909	.35714	.34485	.33020	.33020
$r = 0.30$; percent fuel = 15.027; $\sigma/T = 5.65$												
T, °K	900	1200	1600	2000	2400	2800	3200	3600	4000	b ₃₅₈₈	4400	
F	—	—	—	—	—	—	0.00001	0.00003	0.00037	0.00066	0.00114	
F ₂	—	—	—	—	—	—	—	—	—	.00001	.00001	
H	—	—	—	—	—	—	—	—	—	.00001	.00001	
H ₂	—	—	—	—	—	—	0.00004	0.00007	.00077	.02279	.05004	.08558
HF	0.53846	0.53843	.53790	.53749	.52585	.50971	.48012	.44818	.44500	.42210	.39303	.39303
$r = 0.20$; percent fuel = 20.965; $\sigma/T = 3.77$												
T, °K	900	1200	1600	2000	2400	2800	3200	3600	4000	b ₂₇₅₆	4400	
F	—	—	—	—	—	—	—	—	—	.00002	.00003	
F ₂	—	—	—	—	—	—	—	—	—	.00002	.00003	
H	—	—	—	—	—	—	—	—	—	.00002	.00003	
H ₂	—	—	—	—	—	—	—	—	—	.00002	.00003	
HF	0.66867	0.66867	.66885	.66852	.66437	.65980	.65880	.65563	.65167	.63167	.62063	.62063
$r = 0.15$; percent fuel = 26.128; $\sigma/T = 2.63$												
T, °K	900	1000	1200	1600	2000	2400	2800	3200	3600	b ₂₂₄₂	4400	
F	—	—	—	—	—	—	—	—	—	.00001	.00001	
F ₂	—	—	—	—	—	—	—	—	—	.00001	.00001	
H	—	—	—	—	—	—	—	—	—	.00001	.00001	
H ₂	—	—	—	—	—	—	—	—	—	.00001	.00001	
HF	0.73913	0.73913	.73913	.73912	.73889	.73830	.73830	.73753	.73753	.72607	.72607	.72607

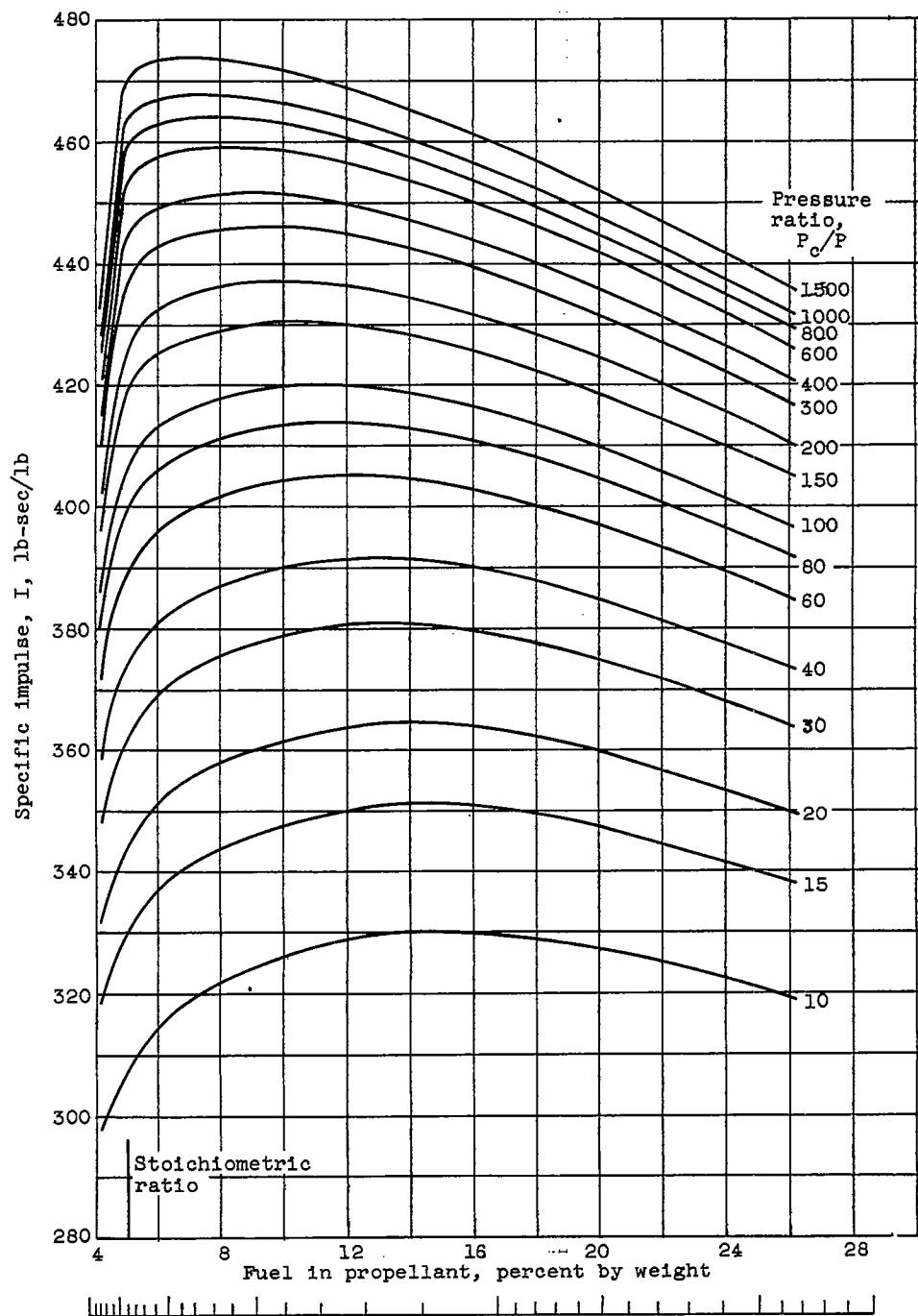
^aMole fractions were computed for all five substances considered in this report but are omitted if less than 5×10^{-5} .

^bCombustion temperature.



(a) Frozen composition.

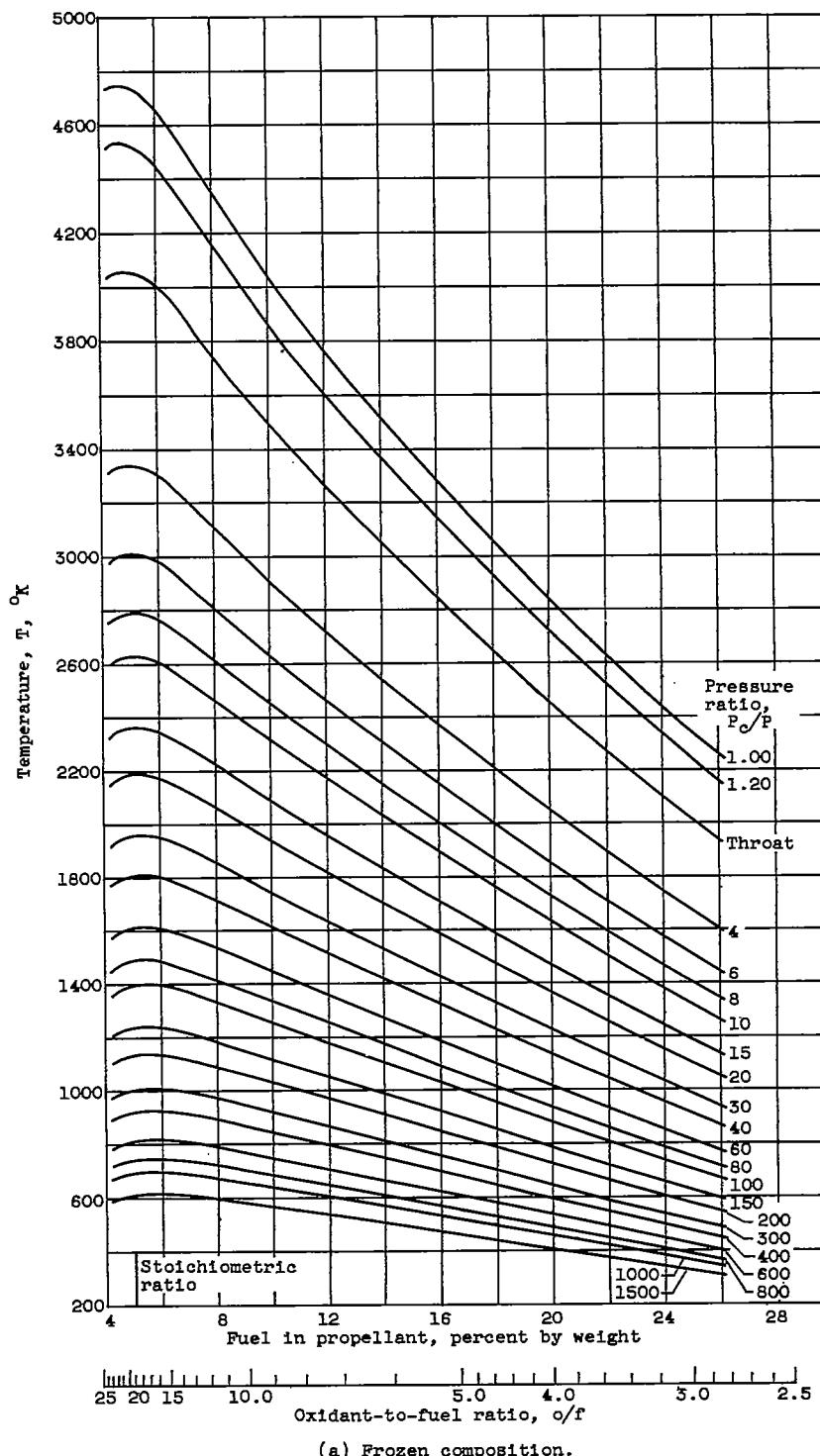
Figure 1. - Theoretical specific impulse for liquid hydrogen with liquid fluorine at a chamber pressure of 600 pounds per square inch absolute with isentropic expansion to indicated pressure ratios.



(b) Equilibrium composition.

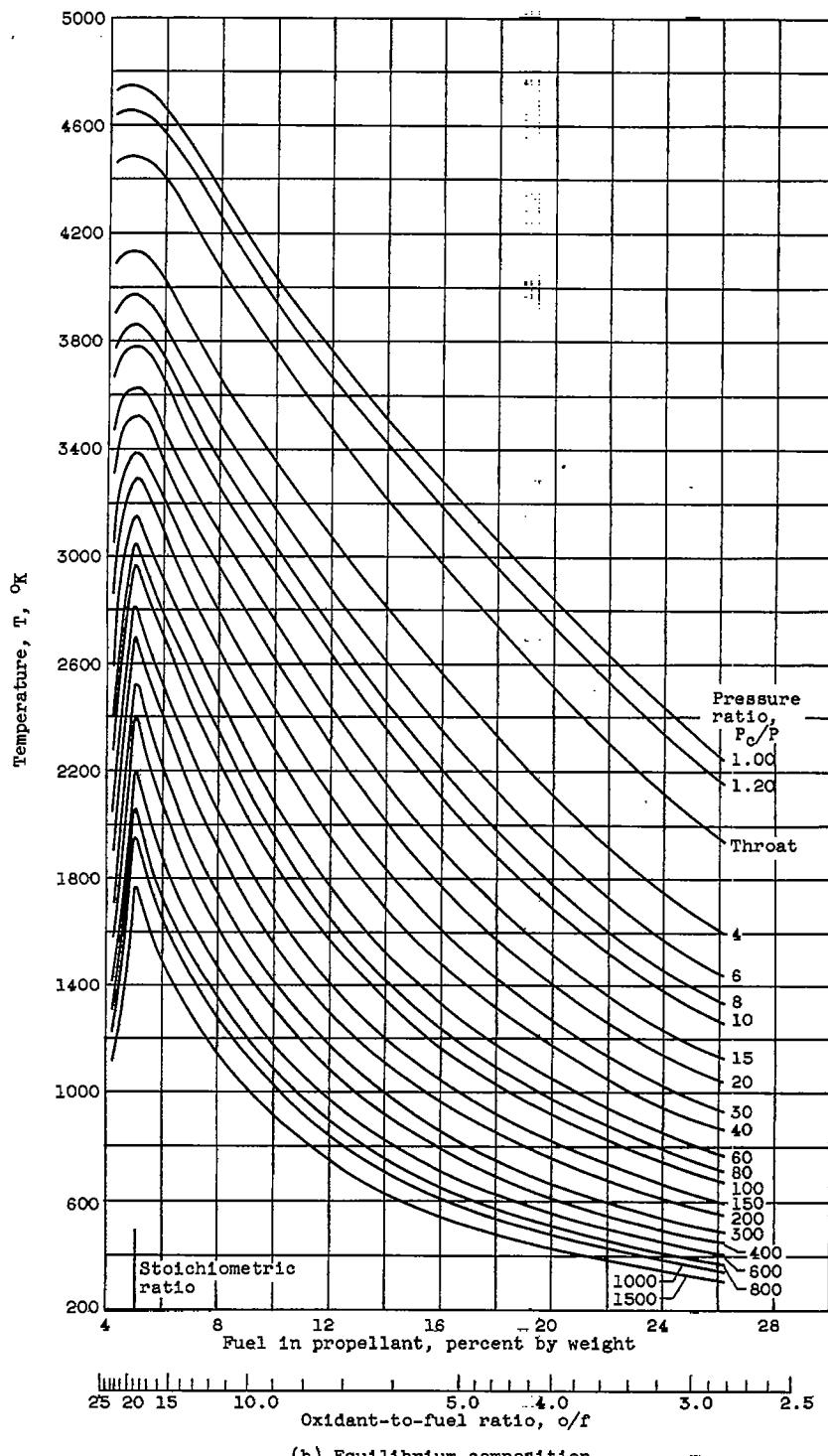
Figure 1. - Concluded. Theoretical specific impulse for liquid hydrogen with liquid fluorine at a chamber pressure of 600 pounds per square inch absolute with isentropic expansion to indicated pressure ratios.

4-346



(a) Frozen composition.

Figure 2. - Theoretical chamber temperature and nozzle-exit temperature for liquid hydrogen with liquid fluorine at a chamber pressure of 600 pounds per square inch absolute with isentropic expansion to indicated pressure ratios.



(b) Equilibrium composition.

Figure 2. - Concluded. Theoretical chamber temperature and nozzle-exit temperature for liquid hydrogen with liquid fluorine at a chamber pressure of 600 pounds per square inch absolute with isentropic expansion to indicated pressure ratios.

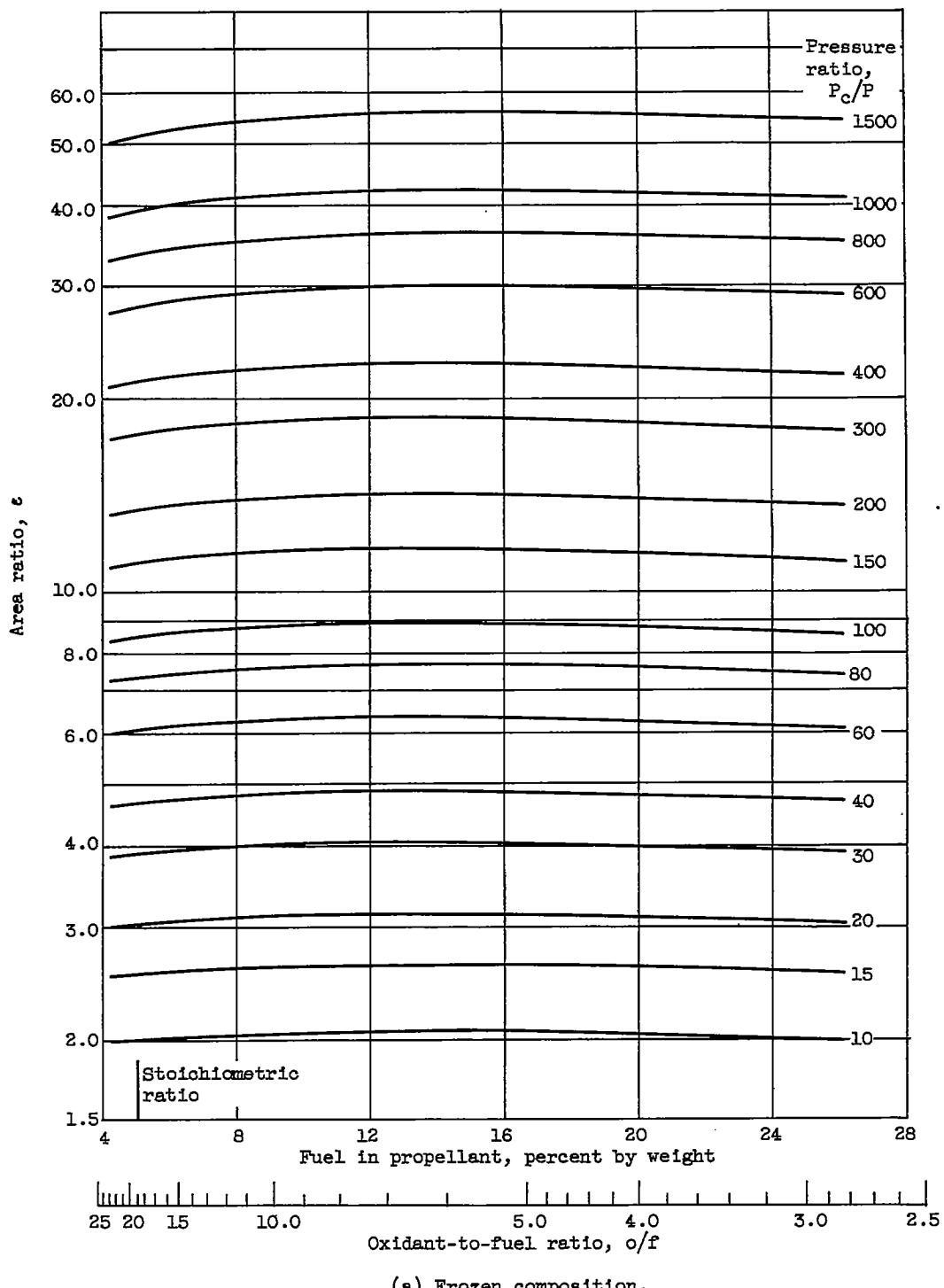
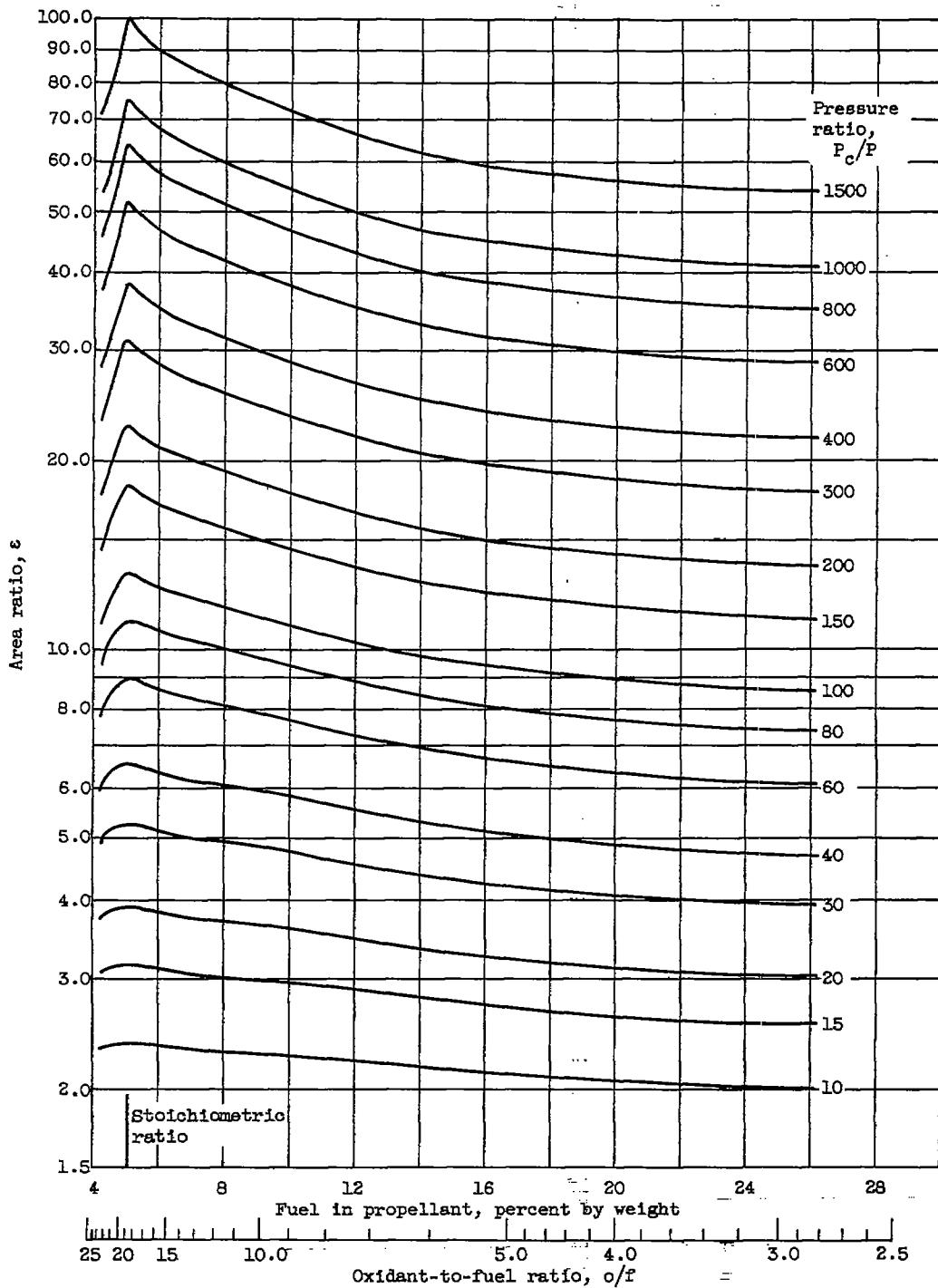


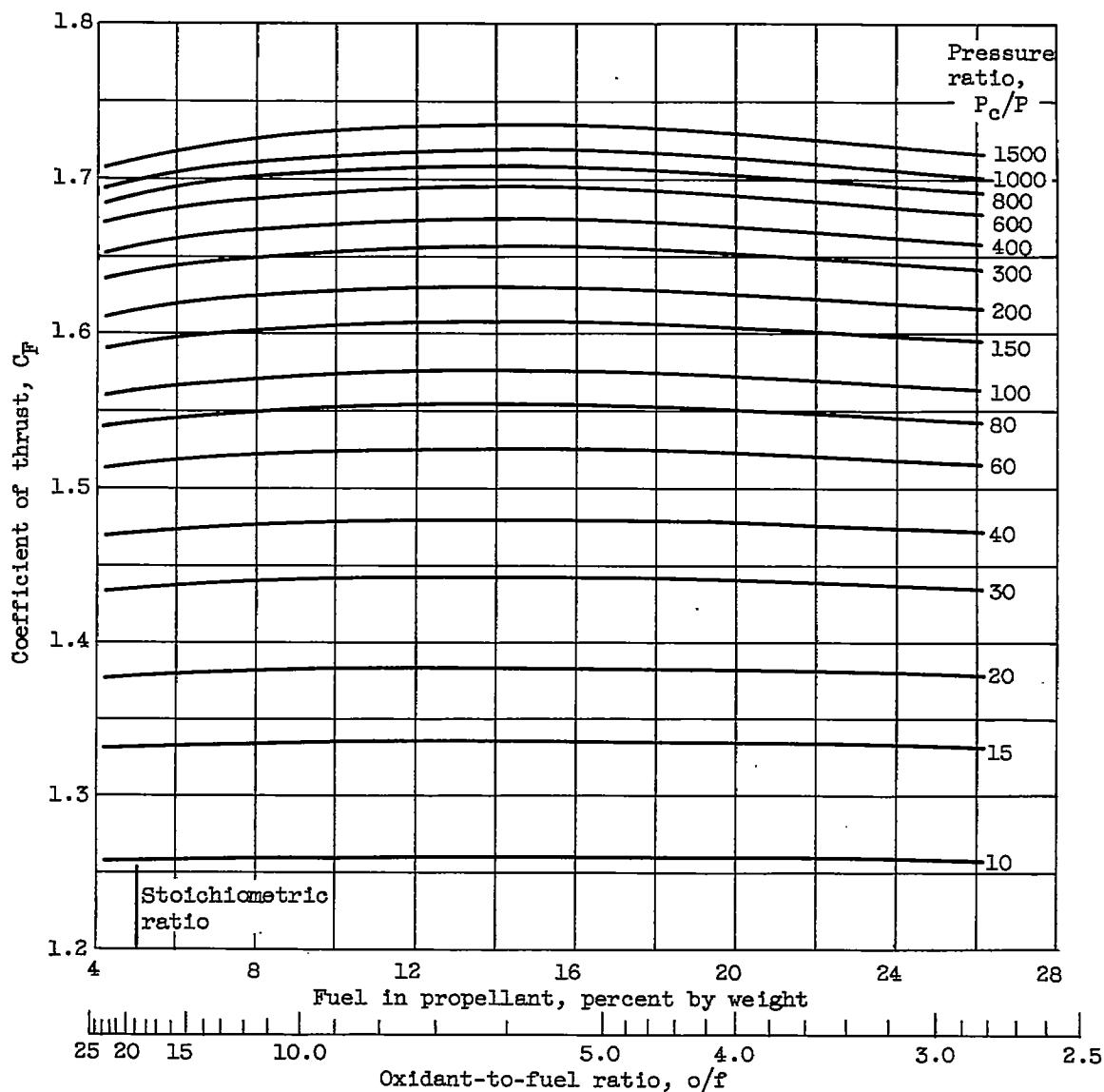
Figure 3. - Theoretical ratio of nozzle area to throat area for liquid hydrogen with liquid fluorine at a chamber pressure of 600 pounds per square inch absolute with isentropic expansion to indicated pressure ratios.



(b) Equilibrium composition.

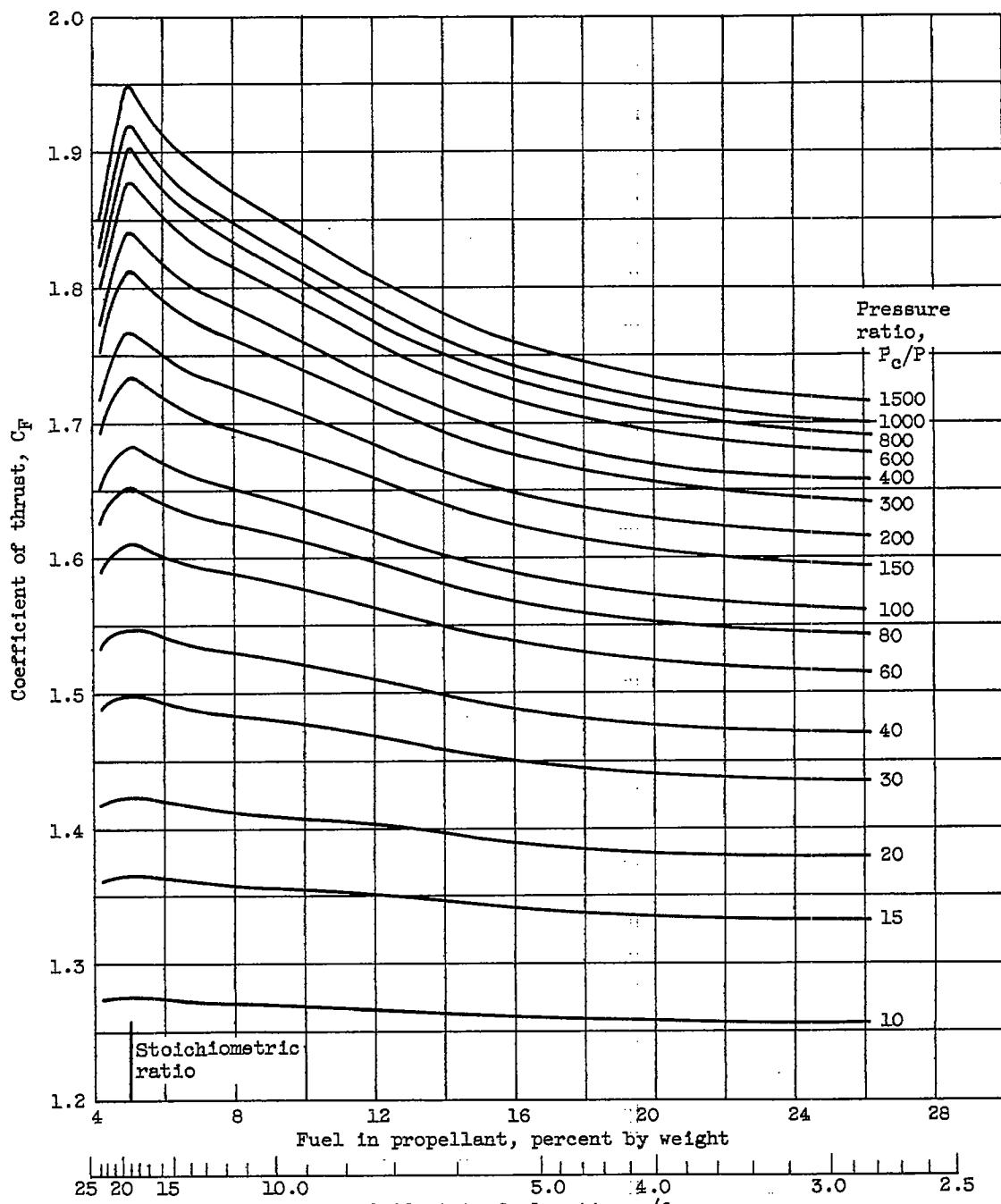
Figure 3. - Concluded. Theoretical ratio of nozzle area to throat area for liquid hydrogen with liquid fluorine at a chamber pressure of 600 pounds per square inch absolute with isentropic expansion to indicated pressure ratios.

434.6



(a) Frozen composition.

Figure 4. - Theoretical coefficient of thrust for liquid hydrogen with liquid fluorine at a chamber pressure of 600 pounds per square inch absolute with isentropic expansion to indicated pressure ratios.



(b) Equilibrium composition.

Figure 4. - Concluded. Theoretical coefficient of thrust for liquid hydrogen with liquid fluorine at a chamber pressure of 600 pounds per square inch absolute with isentropic expansion to indicated pressure ratios.

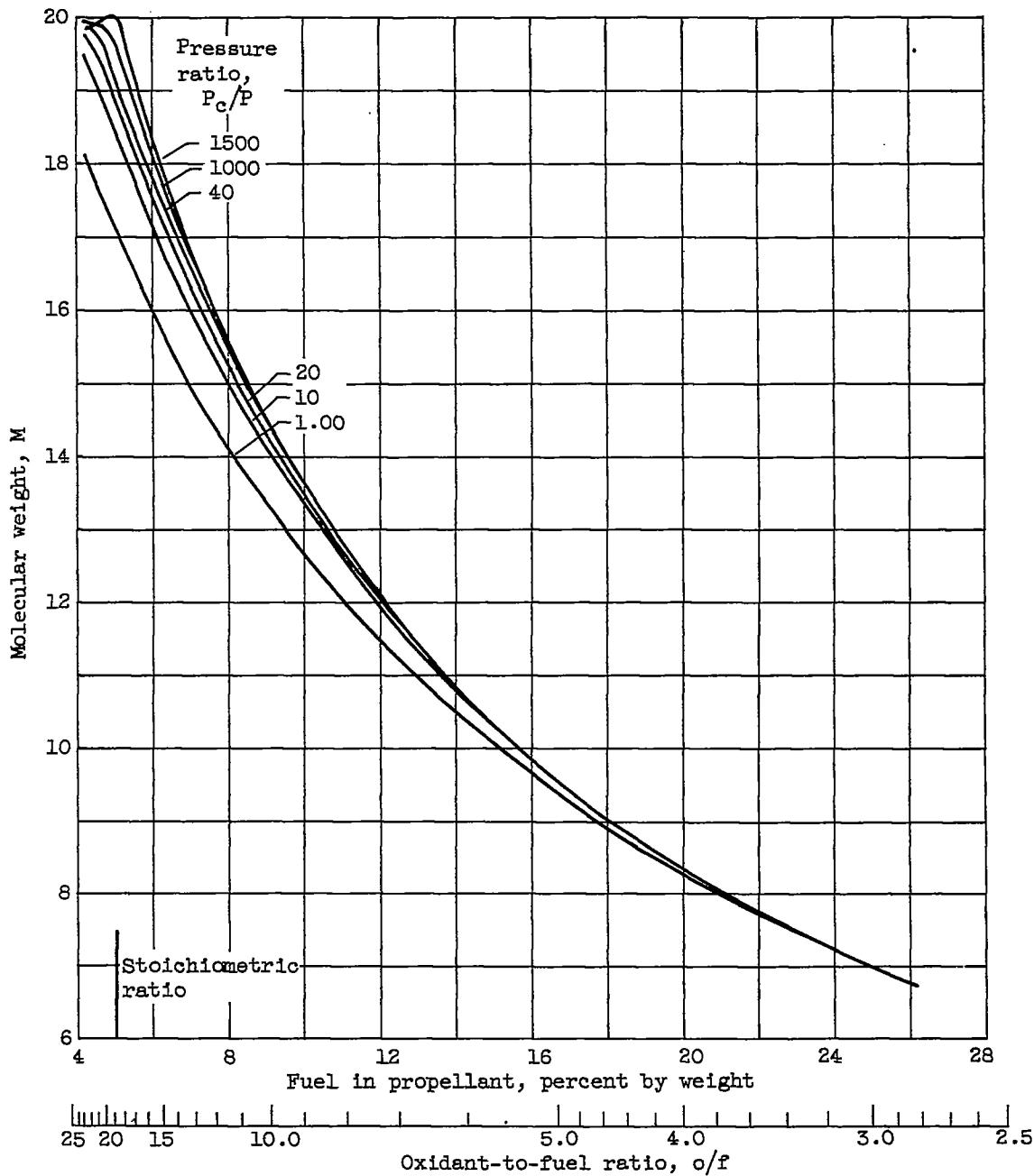


Figure 5. - Theoretical molecular weight for liquid hydrogen with liquid fluorine at a chamber pressure of 600 pounds per square inch absolute with equilibrium composition during isentropic expansion to indicated pressure ratios.

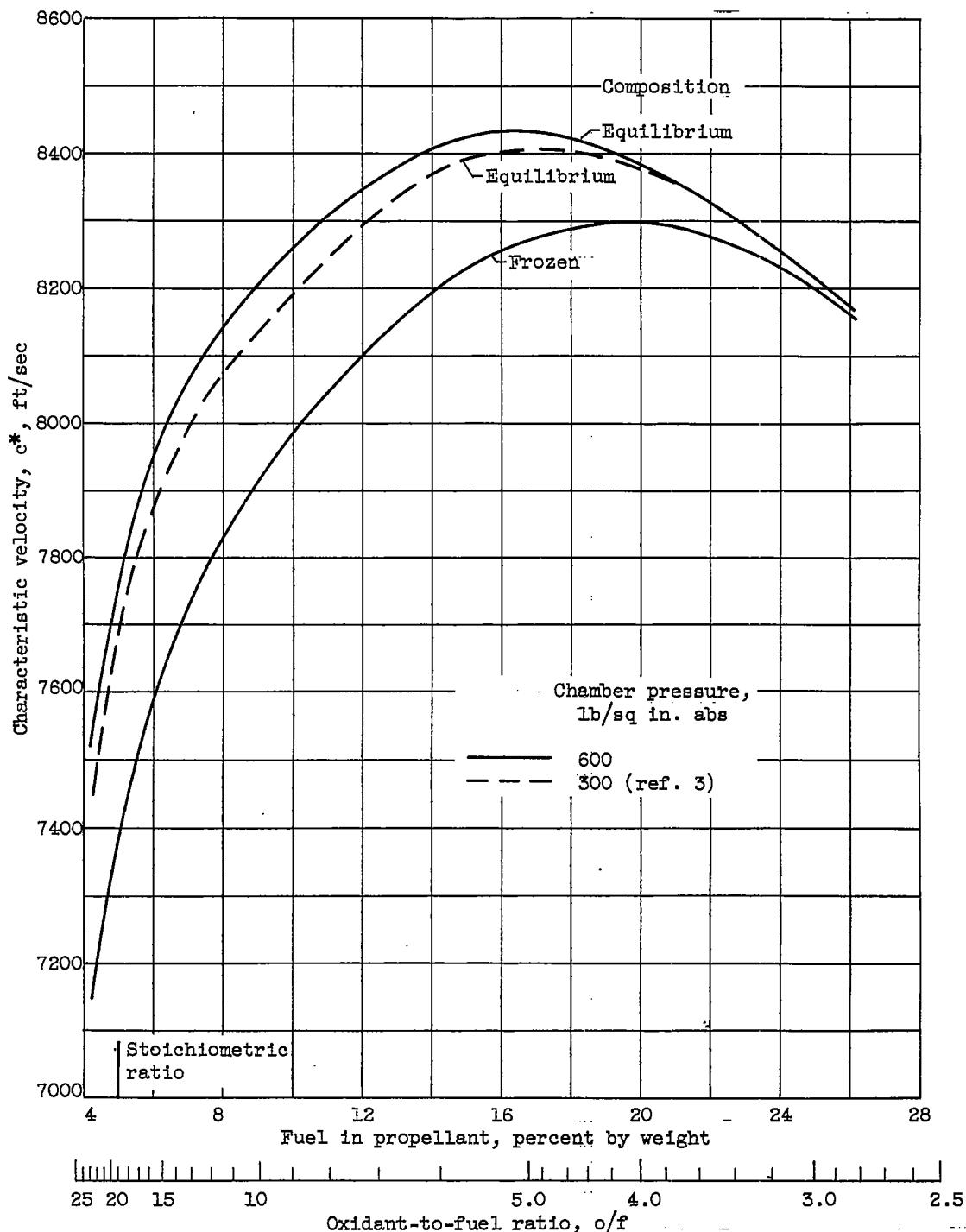


Figure 6. - Comparison of theoretical characteristic velocity assuming frozen and equilibrium composition for liquid hydrogen with liquid fluorine at chamber pressures of 600 and 300 pounds per square inch absolute.

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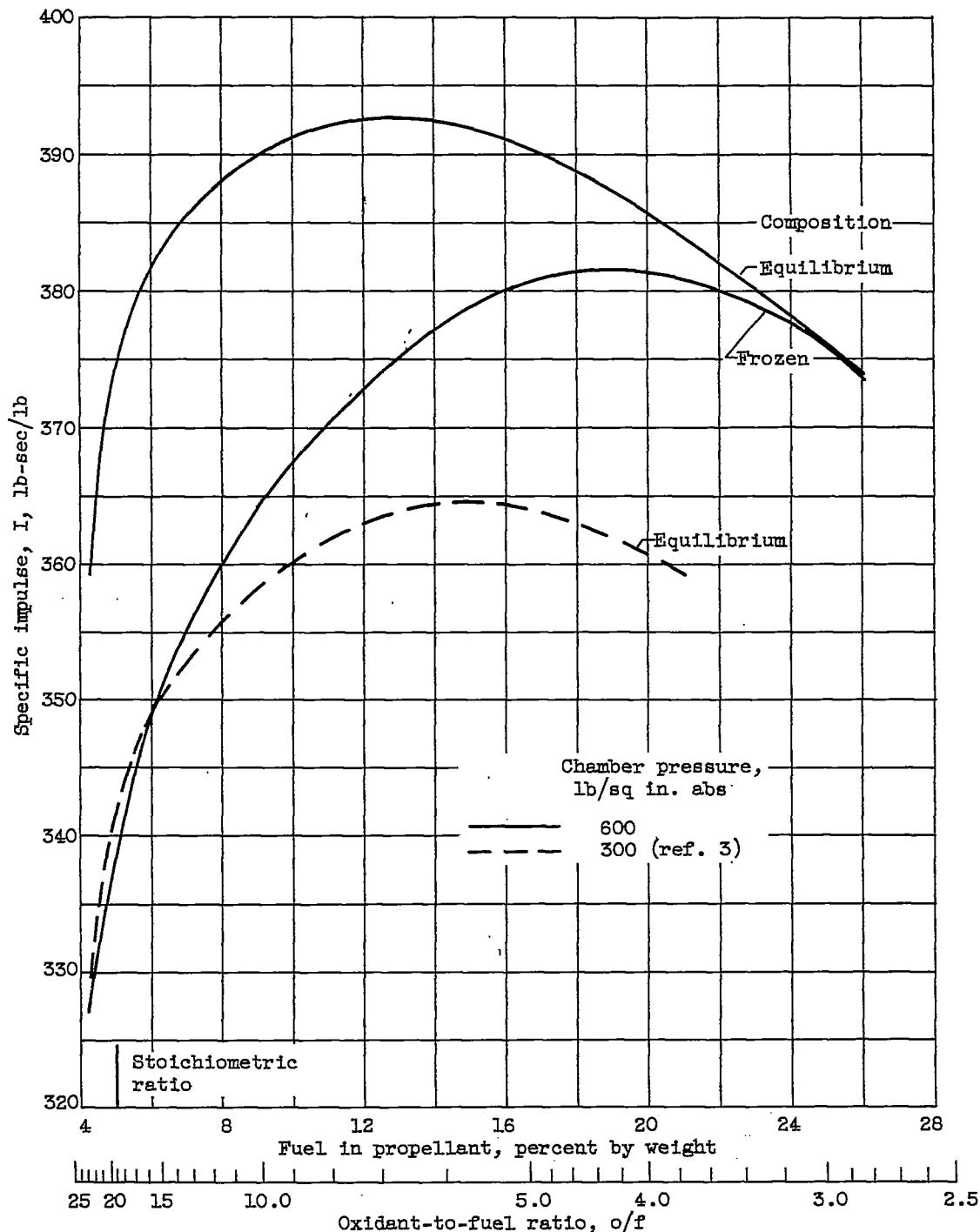


Figure 7. - Comparison of theoretical specific impulse assuming frozen and equilibrium composition. Isentropic expansion to 1 atmosphere; pressure ratio, 40.83 and 20.41 for liquid hydrogen with liquid fluorine.

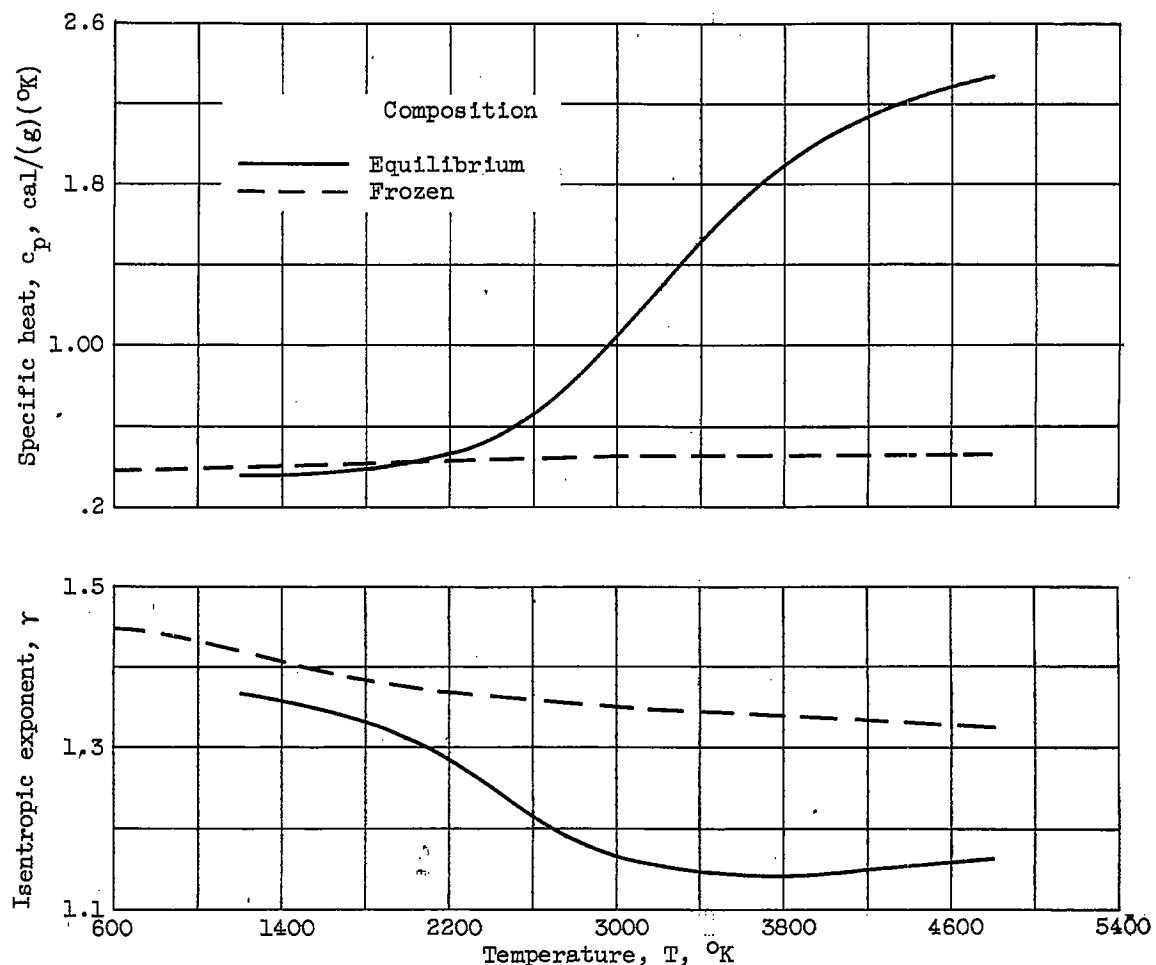


Figure 8. - Variation of theoretical specific heat and isentropic exponent with temperature for both frozen and equilibrium composition. Isentropic expansion; combustion pressure, 600 pounds per square inch absolute; stoichiometric equivalence ratio for liquid hydrogen with liquid fluorine.